Case study: Opportunities for indigenous biodiversity gains within sand dune plantation forestry in Manawatu/Rangitikei

Retained plantation forests, duneland habitats

Prepared for: Manaaki Whenua – Landcare Research

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Peterson P, Simcock R

Manaaki Whenua – Landcare Research

Reviewed by:	*Approved for release by:*
Suzanne Lambie Scientist – Land Use & Ecosystems Manaaki Whenua – Landcare Research	Suzie Greenhalgh Portfolio Leader – Society, Culture & Policy Manaaki Whenua – Landcare Research

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Summary

Project and Client

- This report is an internal case study investigating options to achieve indigenous biodiversity gains within a sand dune plantation forest in the Manawatu/Rangitikei.

Objectives

- Identify options that achieve biodiversity gains within the Tangimoana production forestry landscape.
- Determine the relative financial costs and indigenous biodiversity benefits of each option and use to prioritise options.

Methods

- Information on the natural and human history of the Tangimoana dunelands was collated from websites, reports, modelling, and papers found using google/google scholar searches.
- A field trip involving Graeme La Cock, David Havell, and Samantha Gale (Department of Conservation), Paul Horton (Rangitaane o Manawatu), Pat McCarthy (Ernslaw One Ltd), Robyn Simcock and Paul Peterson (Manaaki Whenua – Landcare Research) was held at Tangimoana forest to discuss past, present, and potential future activities, focusing on biodiversity.
- Expert advice was sought from botanist Dr Jill Rapson (Massey University) who has decades of experience working on sand dune country and its restoration within the Foxton Ecological District.
- Estimates of costs of different options for promoting indigenous biodiversity were determined in consultation with James Sinclair, Ernslaw One Ltd.

Results and Conclusions

- The case study identified four options to enhance native biodiversity within, or adjacent to, Tangimoana forest. Tabulation of costs and benefits considered indigenous biodiversity management and production implications, and ongoing financial costs, allowing options to be ranked.
- Restoration within currently retained 250-ha of plantation forest (the coastal shelter belt) was ranked highest. This includes the creation of pockets of duneland habitats by promoting wetland/swampland, scrubland and native forest, mainly by planting and/or natural regeneration following selective killing of pines to increase light levels. This approach provides medium to longer-term indigenous biodiversity benefits with low management and production implications and costs. This option would incur a one-off cost of ~$8K in the 1st year for tree removal ($4,200), conversion of fire ponds ($2520) and weed and pest control ($4.56/ha) + $15,000/ha for restoration planting. The ongoing cost would be $4.56/ha/yr ($1,140/yr) for weed and pest control.
- The second-ranked option involves connecting the current retained coastal plantation forest to the inland Pukepuke lagoon with a 160-ha ecological corridor. For

landscape-scale benefits, connectivity over space and time needs to be considered alongside creation and protection of a range of dune habitats. This option requires a significant reduction in production forest (with associated lost opportunity costs) but offers landscape-scale benefits that may be unique in the area. Given the depauperate native seed sources, much of the corridor would likely be established by restoration planting once the pine plantation is felled. This option would incur a one-off cost of ~$300,000 in the 1st year for lost opportunity cost ($2000/ha) and weed and pest control ($4.56/ha) + $15,000/ha for restoration planting (unless volunteer). The ongoing cost would be $2000/ha+$4.56/ha (~$300K/yr) for lost opportunity cost and weed and pest control.

- The third ranked option is to refine harvesting methods and replant areas for biodiversity benefits within the productive forest. While this option has relatively low management, production and financial costs, longer-term biodiversity benefits are limited to those species that can move or disperse quickly when areas are harvested. Total ongoing costs are already being spent, for those activities that are practical, but were not defined by Ernslaw One.
- The final option is to facilitate protection and enhancement of the adjacent 152-ha Tawhirihoe Scientific Reserve. Ernslaw One machinery and expertise could be used to assist this neighbouring area where the priority is conservation. However, Ernslaw One prefer to undertake any ‘equivalence work’ within their own estate. This option would incur a one-off cost of ~$5000 in the 1st year for earthworks, tree felling, barrier and signage placement and weed and pest control. Plan preparation and resource consent applications may also be required for earthworks (estimated $20-$50,000). The ongoing cost would be $4.56/ha/yr ($693/yr) for weed and pest control.

Recommendation

Create pockets of duneland habitats within the currently retained plantation forest (coastal shelter belt) at Tangimoana by promoting wetland/swampland, scrubland and native forest. Enhance native seed sources by introducing species that are now rare (e.g. matagouri) with protection from deer for palatable species, and prevent spread of new and existing pest plants, especially along roads and at harvest. Creating these pockets of ecosystems within retained plantation forest could make a valuable contribution to native biodiversity in this highly modified landscape where native ecosystems are sparse.

1 Introduction

Opportunities to promote indigenous biodiversity within non-native plantation forestry landscapes have received limited attention in New Zealand until recently (Forbes et al. 2019; Norton et al. 2020). Most effort and resource to date has been targeted at protecting areas of remnant vegetation with native-dominant canopy, planting native seedlings *de novo* (especially through the 1 Billion trees programme[1]), and at individual species' programmes. There has been less consideration of wider biodiversity values provided by existing non-native plantation forests (Peterson & Hayman 2018). Given that opportunities to enhance native biodiversity can be site-specific, a range of sites and approaches should be considered to see if affordable gains can be made and if generalized approaches can be adopted. We investigated the Tangimoana Forest within the coastal Manawatu-Wanganui Region; a region where landscape modification has been so severe that indigenous plant and animal habitats are now rare and highly fragmented.

Tangimoana Forest lies south of the Rangitikei River mouth within the Foxton Ecological District. It is one of a string of sand-dune, non-native plantation forests running from south Taranaki through Wanganui, Rangitikei, and Manawatu Districts to Horowhenua. These forests, with fore-dunes dominated by non-native marram grass, were established by central, regional, and local authorities from the early 1900s, and by the New Zealand Forest Service from the 1950s. Forests were established to stabilise the naturally moving dunes and prevent sand blowouts caused by wind-blown sand smothering adjacent, highly-productive, farmland. Forest planting continued during the 1980s as part of the 'Foxtangi Sand Stabilisation Scheme' by the New Zealand Forest Service and private owners. Although reduced in extent over the last 20 years due to iron-sand mining, conversion to dairying/cropping, and urban subdivision, these coastal sand dune forests remain extensive, with many being managed by Ernslaw One Limited, a specialist softwood plantation forestry company.

Tangimoana Forest is a small component (837 ha) of Ernslaw One's 6604-ha Rangitikei Sands Forests that include Santoft, Harakeke, Himatangi, Parewanui, and Tree Farm Forests. About 619 ha (74%) of Tangimoana Forest is classified by the company as net stocked area[2] (Ernslaw One Ltd 2018). Ernslaw One is 'committed to creating sustainable softwood forests … for products desired by Pacific Rim consumers'.[3] Within its national estate, which includes over 110,000 ha of forests in Manawatu/Wanganui, Ernslaw One manages rare, threatened, endangered, and recovering species, including kiwi, blue duck, yellow head, native frogs, lizards, *Powelliphanta* snails, brown mudfish, long-tailed bats, and NZ falcon.[4] Ernslaw One is a member of the NZ Forest Owners Association, a signatory to the Forest Accord, and is Forest Stewardship Council-certified. This association, agreement, and certification have been developed to help support environmentally appropriate, socially beneficial, and economically viable management practices for non-

[1] https://www.teururakau.govt.nz/funding-and-programmes/forestry/one-billion-trees-programme/

[2] Net Stocked Area is the area of land in a forest with tree crop on it https://www.forestenterprises.co.nz/faqs/

[3] http://www.ernslaw.co.nz/

[4] https://www.ernslaw.co.nz/environmental-management/

native plantation forestry in New Zealand. For example, Forest Stewardship Council (FSC) guidelines for New Zealand suggest a minimum 10% of each total Management Unit, or equivalent by Ecological District/Region, is managed to retain natural forest, or restored to the condition of natural forest (Forest Stewardship Council 2013). In 2018, Ernslaw exceeded this FSC forest retention goal over its total estate, with 19% protected as formal reserve and retained as natural forest (Table 1). Within this 16,000-ha area, 1065 ha have been identified through an assessment and consultation process as 'High Conservation Value forest'[5], which requires specific management (Ernslaw One Ltd 2018).[6] For the three areas where levels are below 10%, Ernslaw One undertakes 'ecological equivalence' work (see caption below in Table 1).

Table 1 from 2018 Ernslaw One Ltd North Island Environmental Monitoring report

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Ecological District	Reserve Area (ha)	Total area (ha)*	Percentage (%)
Colville	1505.07	7885.84	19.1
Eastern Hawkes Bay	775.02	6970.51	11.1
Foxton	869.57	4911.57	17.7
Heretaunga	117.32	518.34	22.6
Manawatu Gorge South	354.11	850.73	41.6
Manawatu Plains	18.50	423.28	4.4
Matemateaonga	4503.28	7805.71	57.7
Motu	907.55	7334.95	12.4
Pukeamaru	273.10	2113.96	12.9
Puketoi	82.55	943.29	8.8
Rangitikei	658.09	2907.15	22.6
Tongariro	774.52	9475.86	8.2
Waiapu	5416.23	32905.64	16.5
Total	16254.88	85046.83	19.11%

*Total area = planted area + AWR + infrastructure

The National Standard provides an ecological equivalence procedure where percentage shortfalls occur in specific ecological district/region. Pest control and restoration works are currently undertaken in the Manawatu Plains, Tongariro and Puketoi ecological districts where reserve shortfalls are experienced.

AWR = Awaiting Re-stocking

In 2016, Tangimoana Forest land ownership was transferred from the Crown to Rangitāne o Manawatu following settlement of treaty claim WAI 182. Crown lands in parts of the adjacent Santoft and Harakeke Forests were also returned as part of Ngati Apa Claims Treaty settlement in 2010. Although these areas have largely been cleared of native vegetation, they still contain some rare, high-value, remnant indigenous habitats, although

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[5] 'High conservation value forest' is a Forest Stewardship Council forest management designation.

[6] If areas are designated as Recommended Areas for Protection or Protected Management Areas negative effects must be avoided, remedied or mitigated under policy 12.1.2 (Ernslaw One Ltd 2017–18).

these are degraded and fragmented. Generating value from the plantations (owned by Ernslaw One) remains a priority for Rangitāne o Manawatu, but the potential to deliver wider values, such as protecting important mahinga kai wetlands like Pukepuke lagoon, is also being investigated (Wildlands 2017, draft document). The forests and adjacent beaches also have values for dog-sledders, whitebaiters, firewood collectors, researchers, orienteers and recreational hunters of sambar deer, pheasant, quail and waterfowl. Some areas are grazed by stock, and the New Zealand Defence Force has carried out field exercises in the area.

Tangimoana forest was identified as a case study to investigate biodiversity values of plantation forests, particularly the use of retention forestry,[7] because it is part of the Foxton Ecological District. This District has a relatively high proportion of retention (17.7%) forests and has among the lowest remnant indigenous plant cover in the country.[8,9] The dune land and dune slack wetland, dune scrubland and dune forest remnants are also rare within the Manawatu-Wanganui region (Horizons Regional Council 2014), and a relatively large percentage of these occur within plantation forests compared with other regions (Table 2).

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[7] Retention forestry is the practice of setting aside small areas within plantation forest management units for biodiversity benefits and is used in many countries including USA, UK, Canada, Australia, Germany, Sweden, and Argentina (Peterson & Hayman 2018).

[8] https://www.doc.govt.nz/globalassets/documents/science-and-technical/sfc284b.pdf

[9] http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Land/indigenous-cover.aspx)

Table 2. Total wetland vegetation in different land uses[10] (PCL = public conservation land) (Norton & Pannell 2018)

Region	% region in wetland vegetation (area ha)	Percentage of total wetland vegetation in different land uses					
		PCL	Sheep & beef	Dairy	Plantation	Urban	Other
New Zealand	2.1 (556,050)	36.3	0.6	2.4	1.6	0.0	59.1
Northland	1.5 (18,801)	14.5	1.9	6.5	6.4	0.0	70.7
Auckland	1.0 (4,872)	24.2	2.0	6.3	1.2	0.5	65.8
Waikato	4.0 (97,846)	16.5	0.5	2.3	2.8	0.0	77.9
Bay of Plenty	2.1 (25,940)	4.0	1.7	2.2	2.6	0.1	89.5
Gisborne	0.1 (1,243)	0.9	4.1	2.1	3.0	0.0	89.8
Hawke's Bay	0.8 (11,151)	5.8	0.6	0.8	0.9	0.0	92.0
Taranaki	0.3 (2,386)	18.7	1.5	17.7	5.4	0.1	56.6
Manawatu-Wanganui	0.4 (9,880)	28.8	1.6	6.4	8.4	0.0	54.7
Wellington	1.4 (11,394)	72.7	1.1	5.7	0.2	0.1	20.2
Marlborough	0.4 (3,998)	23.9	0.8	10.4	1.2	0.0	63.7
Nelson & Tasman	0.8 (8,057)	78.2	1.0	2.0	1.2	0.0	17.6
West Coast	1.8 (41,078)	77.8	1.3	3.2	0.7	0.0	17.0
Canterbury	2.0 (89,890)	10.2	0.2	1.8	0.0	0.0	87.7
Otago	3.1 (99,158)	6.9	0.4	0.8	2.1	0.0	89.9
Southland	4.1 (130,355)	86.9	0.3	2.0	0.3	0.0	10.5

Tangimoana Forest has potential to develop projects to restore natural sand dune/wetland habitat and associated biodiversity within areas of retained coastal non-native plantation forest that currently acts as shelter belts. These shelter belts are 30–300-m-wide bands of planted pines (see Appendix 1 for scientific names) and macrocarpa that run parallel to the coastline. The approximately 250-ha band protects inland production plantation forest from salt winds and, in combination with marram, minimises the south-easterly migration of sand dunes[11] (Figure 1). Altogether, Ernslaw One maintains about 500 ha of similar coastal shelter belts within the Foxton Ecological District. These shelter belts will never be harvested[12] and from here on are referred to as the 'retained plantation forest'. While marram and retained plantation forest has allowed private landowners to run businesses such as forestry, dairying, and cropping without being adversely impacted by natural dune processes, it has also threatened important sand dune habitats and species within them, especially those adapted to ephemeral wetlands and moving dunes (Rapson 2016) (Figure 2).

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[10] https://beeflambnz.com/sites/default/files/FINAL%20Norton%20Vegetation%20occurence%20sheep%20beef%20farms.pdf

[11] Cowie (1963) estimated annual dune migrations of more than 73 m/year and sand accretion rates of more than 1 m p.a., exacerbated by increased sand deposition by local rivers following inland deforestation.

[12] http://ernslaw.co.nz/assets/resources-north-island/North-Island-Mgmt-Plan-Summary-17-18.pdf

Figure 1. Windward and seaward edge of the shelter belt consisting of non-native pine and macrocarpa trees in the background and marram grass in the foreground.

Figure 2. Foredune, with spinifex and tauhinu on the left and wetland habitat, between Tangimoana and Foxton, that has native 'mudwort' on the right (Rapson et al. 2016).

While retained plantation forest at Tangimoana is primarily a shelter belt, it also provides a coastal barrier within which areas of wetlands/swamps, lakes, scrubland, and native forest could be restored. All these ecosystems were replaced by plantation forestry, farmland, and cropping, and are now all range restricted. Under the new draft Forest Stewardship Council policy (Forest Stewardship Council 2018), the conversion of plantation forests to restored, rare non-forested dune land habitats may qualify as part of the 10% set-aside calculation. The wording in a new draft document (New Zealand Forest Owners Association 2018) has been altered to allow for restoration to *more natural conditions* rather than to just *a natural forest cover*. In areas such as Tangimoana, this approach could deliver regionally- and nationally- significant native biodiversity gains.

In this report we investigate current and potential values of the retained plantation forest and surrounding areas at Tangimoana and explore options to enhance indigenous biodiversity that are environmentally, socially, culturally, and economically viable.

2 Background

New Zealand has lost more than 70% (14 million ha) of its former indigenous forest cover (Ewers 2006), 90% of wetlands[13] (Ausseil et al. 2011), and 70% of active dunelands (Hilton et al. 2000). Plantation forestry (mostly *Pinus radiata*) has replaced some of these, now covering approximately 6% (1.7 million ha) of New Zealand. In 2018, 35 million m^3 of wood was harvested from plantation forests, an increase of 10% on the previous year, and over ½ million ha will be harvested in the next decade due to a 'wall of wood' resulting from extensive plantings in the 1990s (New Zealand Forest Owners Association 2018). Harvesting trees causes large-scale landscape changes, most notably the loss of canopy, soil displacement and compaction, and loss of most above-ground indigenous biodiversity within the clear-felled areas. Harvesting can also damage adjacent remnant native habitats and open up ground where invasive weeds such as pampas, gorse and broom can rapidly establish. However, when a pine canopy is established, these shade-intolerant weeds are supressed and some native plant species establish, depending on light, moisture-stress, seed sources, and browsing pressure. Established plantation forests can also buffer and connect remnants while providing habitat for some native plant and animal species (Brockerhoff et al. 2008).

Specific rules within the National Environmental Standard for Plantation Forests (NES-PF) are designed to help minimise potential negative impacts from large scale harvesting operations and establishment of new plantations (New Zealand Government 2017). The standard requires assessments of the risk of adverse environmental impacts linked with erosion, freshwater fish spawning, and wilding trees. However, there is negligible protection within the standards for native terrestrial biodiversity values apart from indigenous vegetation clearance limitations for any area greater than 1 ha and a short section on indigenous bird nesting. Protection of indigenous bats, frogs, reptiles, and invertebrates is not specifically mentioned in the NPS-PF (Peterson & Hayman 2018). However, a long-delayed draft National Policy Statement for Indigenous Biodiversity (NPS-IB, Ministry for the Environment 2019[14]) is likely to require regional councils and territorial authorities to enhance protection of native biodiversity on private lands. The NES-PF has a

[13] Only 4.9% remains in the North Island by 2008; see interactive maps at this website http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Fresh%20water/wetland-extent/wetland-extent-archived-27-04-2017.aspx

[14] https://www.mfe.govt.nz/publications/biodiversity/draft-national-policy-statement-indigenous-biodiversity

provision that recognises the value of indigenous vegetation as corridors, but not plantation forests (section 94); however, the draft NPS-IB includes provisions to protect native biodiversity in plantation forestry of which much is on private land, and also establishes a target of more than 10% indigenous plant cover in urban areas, mirroring the minimum requirement in FSC-certified plantations. Within plantations, high-erosion prone areas, defined as red zones in the NES-PF are also targets for native regeneration (Lambie et al. 2018).

While most New Zealand forest companies have species management plans that are applied to forest areas where rare, endangered, and threatened native species are known to be present, areas without visible 'flagship' species or tall forest vegetation are generally not prioritized for biodiversity conservation. Cryptic species such as bats, lizards, and many invertebrates are unlikely to be identified without specific, specialist surveys. In fact, less than one half of invertebrate species in New Zealand have even been described (MfE 1997, https://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/invertebrates/systematics). Further, there is little incentive to fund such specialist surveys given outcomes are likely to add cost or reduce revenue from harvesting operations, especially if species subject to wildlife permits are discovered. Despite this, some forestry companies have supported surveys to find and monitor rare species such as Travers' land snail (*Powelliphanta traversi*) at its strongholds of Shannon Forest (Earnslaw One Ltd) and Kohitere Forest (Rayonier NZ Ltd, Turner 2011[15]) and mudfish at Santoft dune forest (Ernslaw One 2010[16]). However, in general, 'biotic inventory and monitoring in New Zealand is largely uncoordinated and underdeveloped' (Walker et al. 2006).

Although indigenous biodiversity in general benefits where high profile species are promoted through habitat protection, areas with high indigenous values can be small and/or disconnected, as noted for lizards and peripatus[17] in urban areas (Constantine 2011; NZTA 2017). There may also be confounding impacts (Ewers 2005), i.e. edge creation for New Zealand Falcons (Seaton et al. 2010, 2013; Thomas et al. 2010; Horikoshi et al. 2017) may disadvantage other indigenous species. Protecting and enhancing representative habitats is a complementary approach to individual species' focus when conserving indigenous biodiversity. This approach was the intention of the Protected Natural Areas Programme set up in 1983 (Technical Advisory Group 1986), which identified representative examples of most biological systems (Kelly & Park 1986). However, in areas such as the Manawatu-Wanganui plains, where little native biodiversity remains, protecting representative indigenous biodiversity also requires restoring and creating new habitats. Here, retained plantation forests may play valuable roles, although

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[15] Turner describes the 620-ha forest, of which 352 ha was pine plantation; the surveys and management were focused on native vegetation.

[16] Ernslaw One describes exclusion of stock and machinery, and planting of manuka and flax within a 5-m riparian buffer zone around identified 'mudfish wetlands' and 15-m buffer zone where no desiccant herbicides are applied https://www.ernslaw.co.nz/assets/resources-contractors/EMS/RTE/Brown-Mudfish-Identitfication-and-Management-Jan-2010.pdf.

[17] Constantine 2011 https://www.odt.co.nz/news/dunedin/rotten-log-yields-living-fossil-find; NZTA 2017 https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Biodiversity/Case-studies-and-research/BD-002-Peripatus-Translocation-case-study.pdf

expectations must be compatible with the context within which these landscapes now occur (Norton & Miller 2000). In Manawatu-Wanganui sand country, the very young dune soils combined with simple hydrology and vegetation favour effective restoration (Murphy et al. 2019).

Together the long-term management by an experienced FSC-certified company combined with change to iwi land-ownership, change in FSC policy to 'count' restoration of non-forest ecosystems (such as wetlands and dunes), and a draft NPS-IB that promotes restoration targets for biodiversity in depauperate areas, enhance opportunities to promote indigenous biodiversity within these sand-country plantation landscapes. Favourable biodiversity outcomes will be best achieved by pre-determining where best to restore areas to maximise future long-term benefits.

2.1 Biodiversity values of plantation forests

Non-native, plantation forests can provide and support a range of native plant, animal, and fungal biodiversity values. 'Plantations sometimes contain diverse (plant) species assemblages, including a high indigenous component' (Allen et al. 1995) and 'indigenous understoreys in plantation stands can be diverse and well-developed' (Maunder et al. 2005). Stand age is the primary control on species richness with topography and soil type being secondary (Ogden et al. 1997). Stand density (ground-level light levels), rainfall, and proximity to seed sources also influence native plant species richness (Forbes et al. 2019). Even at ecologically isolated sites, plantations create conditions that may support a range of readily dispersed native forest plants (Forbes et al. 2019). Such conditions include shade and reduced competition from faster-growing non-native species, and may include exclusion of stock and other browsers, especially for plantations developed on farms.

Plantation forests can also provide suitable habitat for many native New Zealand animal species (Maunder et al. 2005; Brockerhoff et al. 2008; Pawson et al. 2010; Quine & Humphrey 2010; O'Hanlon 2011; Pawson et al. 2013), especially when native plant representation is high (Peralta et al. 2018), and for indigenous forest communities in general (Forbes et al. 2019) (also see Appendix 2). Pawson et al. (2010) list 118 threatened species of flora and fauna recorded or observed within plantation forests.

Retained plantation forests can provide important opportunities for restoration to indigenous forest cover; Forbes (2015) reports degraded pine plantation canopy provided suitable conditions for development of a native podocarp dominated forest within ca 50 years of underplanting at Kaingaroa, Central North Island. Reversion of non-native plantation forests to indigenous forest can be accelerated by creating suitably sized canopy gaps and inter-planting specific indigenous canopy species (Forbes et al. 2016). Native forest and shrubland regeneration through pine canopies has also been accelerated by ground- and/or aerial- herbicide application across New Zealand. However, success has been variable, depending largely on pine form, size, and density, presence of native plants, competing non-native plants that are 'released' post-harvest, and browsing pressure particularly by deer and goats.[18] Aerial herbicide applications to control non-native plants disadvantage some native species, with some herbicides favouring manuka/kanuka (Harrington et al. 2015).

Most above-ground biodiversity values within stands are obviously lost when plantations are clear-fell harvested. However, methods have been trialled to retain and promote biodiversity under clear-felling regimes, such as leaving individual trees, patch harvesting, wood stack retention, nest/roost avoidance, and seasonal felling. These can help reduce negative impacts on some fauna, but often target individual native species (Peterson & Hayman 2018). Another emerging technique is the adaption of European 'continuous cover forestry' to New Zealand native and non-native species (Benecke 1996; Barton 2008). In these systems, low-impact harvesting (with pruning and releasing) is carried out each year using small pocket or single-tree extraction through the whole forest, and natural regeneration practiced. Key biodiversity benefits of this approach, alongside the avoidance of clear-felling, include increased diversity of forest structure, usually combined with a diversity of tree species.

2.2 Retention forestry

Internationally, the most effective method for protecting native biodiversity within production forestry landscapes is retention forestry (Peterson & Hayman 2018). This involves deliberately not harvesting about 3–30% of a production forest management unit (Fredowitz et al. 2014). This retention of intact pockets of forest maintains areas of less-disturbed forest cover and delivers a more complex forest structure. In central Europe, the term includes targeting older trees with hollows and cracks and dead wood (as snags and logs) for habitat provision within production forest cover (Storch et al. 2020). Such features are critical for animals that use cavities, and for epiphytic plants, lichens, and saproxylic invertebrates. Despite retention forestry being a widely applied management practice internationally (Fredowitz et al. 2014), it has received limited attention in New Zealand, partly because nearly all New Zealand plantations are non-native species that are clear-felled (Peterson & Hayman 2018). However, retained non-native plantation forest could play an important role across New Zealand landscapes by providing areas for native forest restoration, buffers around non-forested land or native remnants, and/or connectivity between remnants for indigenous forest biodiversity where historical land clearance has been extensive (Forbes et al. 2015, 2019; Peterson & Hayman 2018). The landscape-level 'Cape-to-City' restoration project identified exotic forest plantations as a substantial proportion of (native) bird habitat, and important for both habitat and connectivity, recommending that some mature plantations in the northern area be retained (Burge et al.

[18] E.g., Marlborough Sounds Restoration Trust, Project Janszoon in Abel Tasman National Park, and ForestlifeForce Trust's Maungataniwha project https://www.marlborough.govt.nz/repository/libraries/id:1w1mps0ir17q9sgxanf9/hierarchy/Documents/Environment/Biodiversity/Guidelines%20for%20Pine%20Plantations%20List/B%20Pines_to_Native_Guidelines_Website_PV.pdf

2017[19]). When these forests were felled, McLennan and Nakagawa (2019[20]) reported that the absence of these valuable stepping stones not only removed valuable habitat for small insectivorous native birds in the landscape, but also meant it is now doubtful whiteheads and tomtits will ever move naturally from Cape Sanctuary'.

The potential positive ecological contributions of indigenous remnants and retained plantation forests in New Zealand are already recognised by the Forest Stewardship Council (FSC) who specify minimum standards for retention for forest companies to gain certification. These include the option of converting current plantations to non-harvest 'retained areas' where historical land clearance has been extensive, and no natural forest cover exists (Forest Stewardship Council 2013). In this case study we investigate options for promoting indigenous biodiversity within the Tangimoana landscape, which includes a significant area of retained plantation forest. We investigate how and where the goals of biodiversity conservation and wood production can be combined, and the likely trade-offs.

3 Objectives

- Identify options for creating biodiversity gains within the Tangimoana production forestry landscape.
- Determine the relative financial costs and indigenous biodiversity benefits of each option.

4 Methods

- Information on the natural and human history of the Tangimoana dunelands was collated from websites, reports, modelling, and papers found using google/google scholar searches.
- A site visit with Graeme La Cock, David Havell, and Samantha Gale (Department of Conservation), Paul Horton (Rangitaane o Manawatu), Pat McCarthy (Ernslaw One Ltd), Robyn Simcock and Paul Peterson (Manaaki Whenua – Landcare Research) which was held at Tangimoana forest to discuss past, presen, and potential future activites, focusing on biodiversity.
- Expert advice was sought from botanist Dr Jill Rapson (Massey University) who has decades of experience working on sand dune country and its restoration within the Foxton Ecological District.
- Estimates of costs of different options for promoting indigenous biodiversity were determined in consultation with James Sinclair, Ernslaw One Ltd.

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[19] Burge OR, Innes J, Fitzgerald N, Richardson S 2017. Habitat availability for native New Zealand bird species in the Cape-to-City footprint: a preliminary assessment. Landcare Research Report LC2898.

[20] McLennan J, Nakagawa K 2019. Bird counts Cape to City project, Hawke's Bay. Environmental Services Ltd.

5 Results

Past and present duneland dynamics and vegetation, and existing and potential opportunities to increase indigenous biodiversity within the Tangimoana Forest and adjacent Tawhirihoe Scientific Reserve were assessed. Estimated costs and acceptability of different approaches were compared.

5.1 Study area

Tangimoana Forest is a plantation forest within the Foxton Ecological District between the outlet of the Rangitikei River and Himatangi Beach township. It includes a strip of retained plantation forest that acts as a coastal shelter belt and barrier to inland sand movement, protecting productive plantation forest and farmland. Tangimoana Forest is adjacent to the Tawhirihoe Scientific Reserve, one of the last remaining examples of the dynamic dune ecosystem that once ran the length of the Foxton Ecological District (Figure 3). The Reserve has been well-studied (Singers 1997; Rapson et al. 2016; and Murphy et al. 2019) and provides a local template of information on indigenous biodiversity and habitat formation to inform creation of similar habitats within and adjacent to the Tangimoana Forest. Pukepuke lagoon, an inland dune lake, is another important local feature.

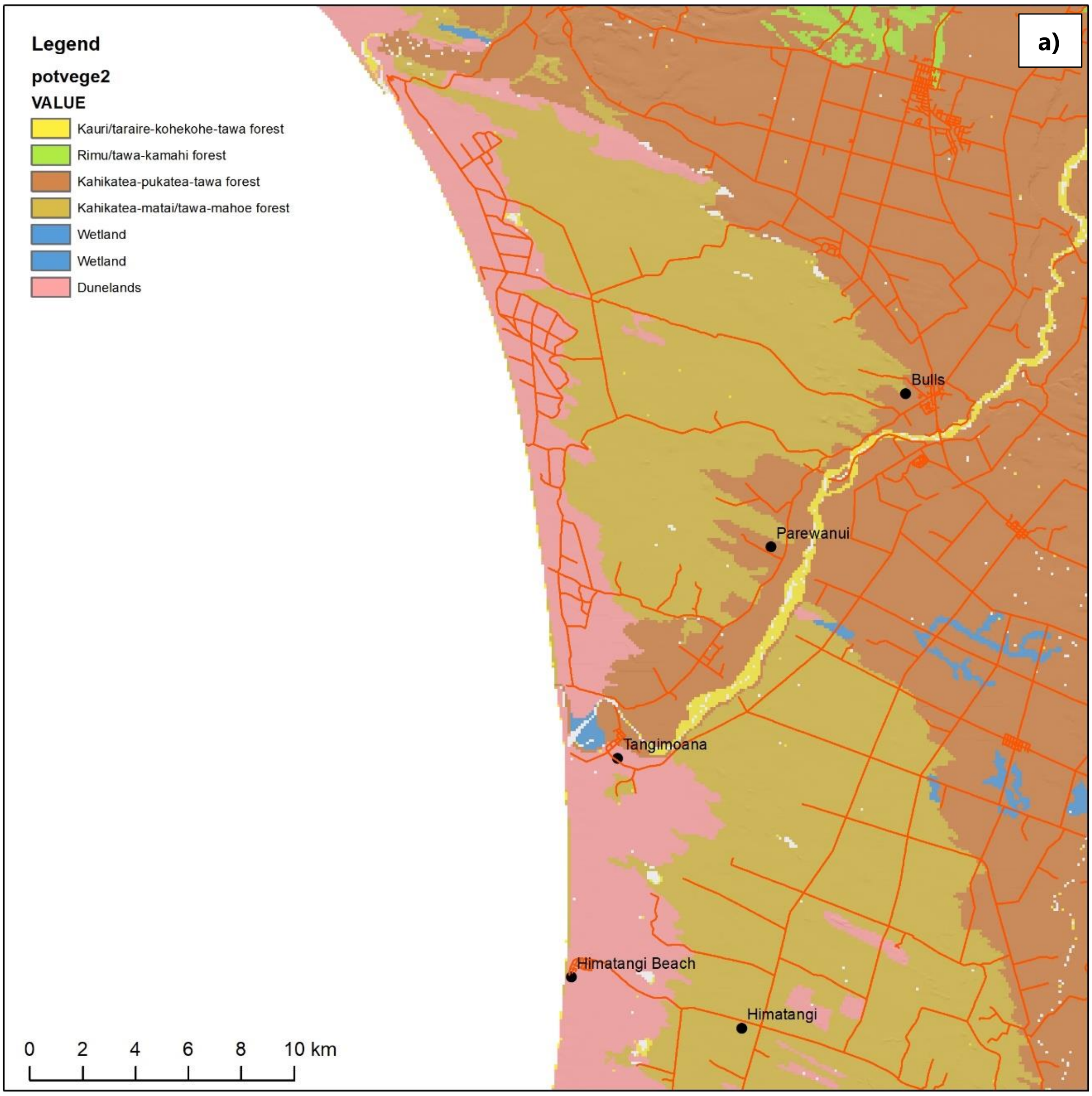
Figure 3. Map showing Tangimoana productive plantation forest, the retained plantation forest strip, Tawhirihoe Scientific Reserve, and Pukepuke lagoon.

5.2 Past and present duneland dynamics and vegetation

This section reviews the natural pre-human duneland vegetation, with a focus on the types and proximity of vegetation types, as this informs the management and potential values of the existing retained plantation forest. A description of duneland dynamics identifies ecosystems and management that could be compatible with forest production cycles.

Information about the original pre-human vegetation within the Foxton Ecological District is sparse. McGlone (1989) suggests Manawatu lowlands were vegetated with tall conifer-broadleaf forest 3000 years ago. At a finer scale, Hesp (2001) proposes that while the inland dunefields were largely forested, the more seaward dunes would have been a mosaic of kahikatea, tōtara, and cabbage tree dominated swamp, and deflation-plain forest with Tawa dominated forest on drier sites, kānuka and mānuka on the younger stabilized dune ridges, and toetoe and scrub on the recently active dunes. At an even finer scale, Ravine (1992) provides a comprehensive insight into pre-human vegetation suggesting a more stable coastline with foredunes with sea-ward slopes of spinifex and pīngao. On the fore-dune lea-slopes, shrubs such as tauhinu, sand coprosma and possibly matagouri would have been numerous, with some sand daphne and club sedge. Younger dune hollows and sand plains would support low-stature sedges and herbs, while older areas would have been covered in jointed wire-rush, toetoe, cabbage trees, and flax. Ravine (1992) considers within a kilometre of the sea shrubs (coprosmas, poataniwha and native broom) and forest would be found: akeake, rewarewa, tītoki, ngaio and māhoe with at least some tōtara and mataī. Further inland there would have been a greater forest diversity with species such as tawa, turepo, hīnau, kaikōmako and even northern rātā and kāmahi. In swamps, kahikatea, pukatea and rimu would have dominated.

Pollen analysis supports the presence of pre-human forests less than 1 km from the nearby Paekakariki coastline, dominated by podocarp trees, including rimu, mataī, miro, lowland tōtara and kahikatea, and a range of angiosperms, including northern rātā, swamp maire, tawa, rewarewa, mānuka, kānuka, pukatea, kohekohe, and cabbage tree (Wilmshurst & Bolstridge 2019). Modelling indicates kahikatea-mataī/tawa-mahoe forest approaching the coastline at Tangimoana and growing around Pukepuke lagoon near the Tangimoana study site before human arrival (Leathwick 2001). See Figure 4 and Appendix 3 for predicted past and present vegetation maps of this area.



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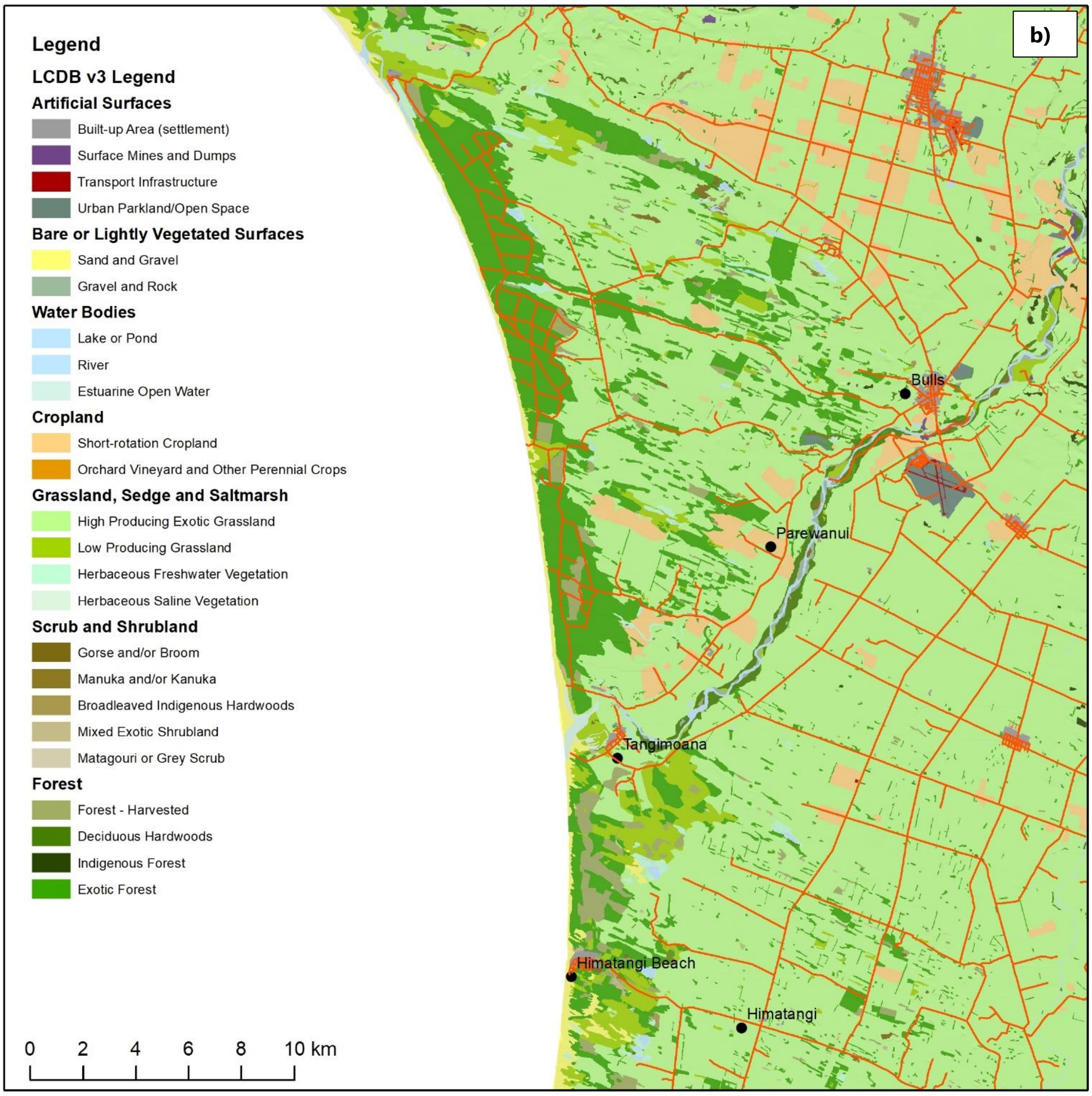

Figure 4 a) Predicted past (Leathwick 2001) and b) present (land cover database LCDB4.1, Manaaki Whenua – Landcare Research 2015 https://lris.scinfo.org.nz/layer/48423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/) vegetation maps.

No definitive evidence identifies how close forest grew to the sea along the Foxtangi coastline (Tangimoana to Foxton) between the dune-building phases identified by Cowie (1963), but traces of Maori occupation and one large stump about 750 years old were found under sands of the Motuiti Phase (500–1000 years old) several miles[21] from the coast (Cowie 1963). Early European references describe open grassy flats and ridges interspersed with areas of mānuka, bracken, tutu, rushes, toetoe, and flax (Singers 1997), and Burgess (1984) considered his field site was largely in a 'pristine' (pre-European) state (Singers 1997). However, this is unlikely to be representative of the natural state, as fires associated with (pre-European) Maori occupation were probably responsible for removing

[21] Due to sand dune accretion and coastline expansion over time, it is difficult to know how much closer to the coast this tree would have been when alive.

the original vegetation, initiating the Motuiti dune building phase 500–1000 years BP. More recently, overgrazing and burning by European settlers may have led to the Waitarere dune building phase <100 years BP (Cowie 1963; Hesp 2001) (Figure 5). Aerial photographs from Hesp (2001) show dramatic vegetation changes just south of the Tangimoana study site, between Himatangi and 3 Mile Creek, where the impacts of pre-1940s vegetation removal through burning and grazing resulted in large scale sand sheets and transgressive dunefields dominating the landscape. See Figure 6 for an example of transgressive dune formation. From the 1940s to the 1990s partially successful attempts were made to tame 'the sand menace', resulting in a change from transgressive, mobile sand dunefields to largely vegetated parabolic dunefields in areas that were settled, forested or farmed, and, more recently, to intact foredunes with occasional blowouts, which sometimes develop into long parabolic dunes (Figure 7).

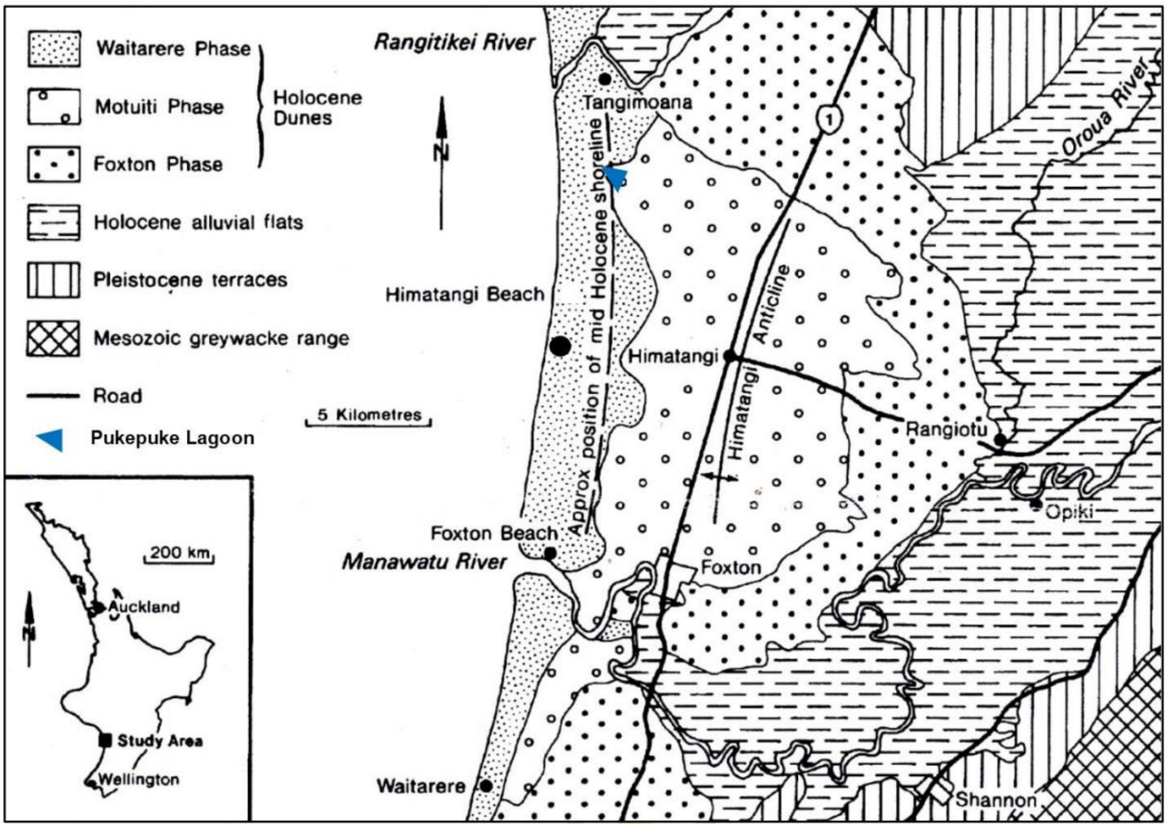

Figure 5. Manawatu dune-building phases based largely upon soil development from Cowie (1963) from Shand (2017).

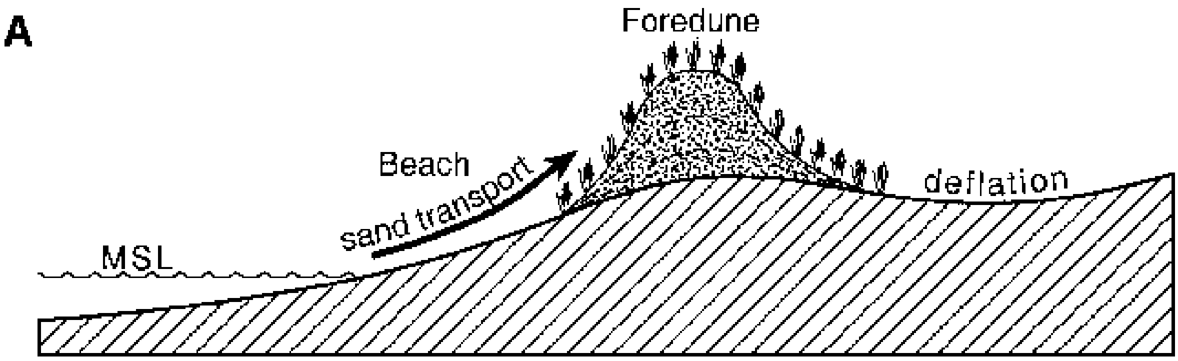

Figure 6. Generalized image of a) before and b) after transgressive dune formation (Tsoar 2000).

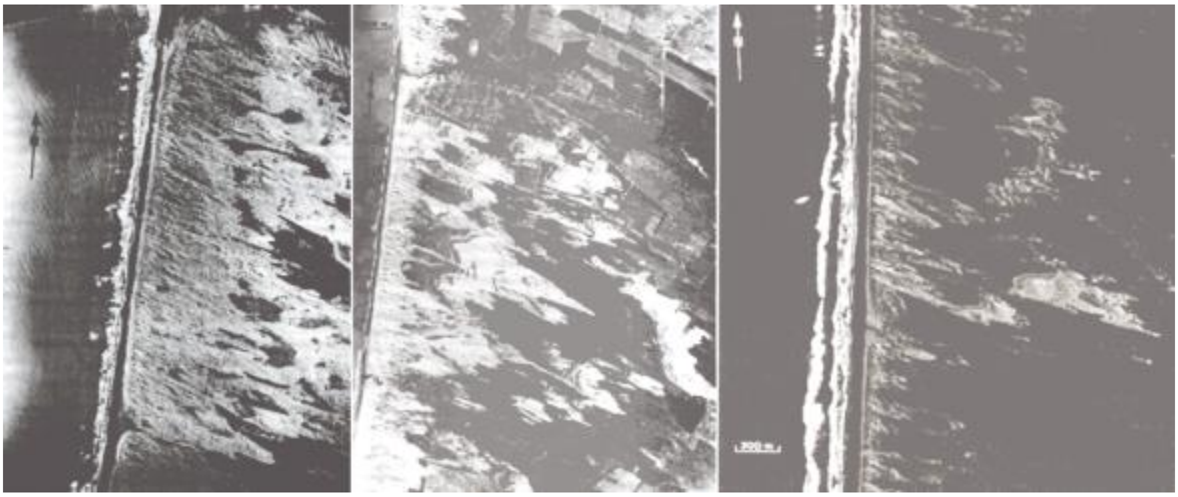

Figure 7. Series of photos between Himatangi and 3 Mile Creek showing large scale sand sheets and transgressive dunefields in 1942 following vegetation removal by burning and grazing (far left); break up of transgressive dunefields into large parabolic dunes in 1979 following dune stabilization work with marram and non-native forest (middle); and, relatively intact foredune with blowouts which develop into long parabolic dunes with much of the remaining dunefields in plantation forestry or pasture in 2000 (right).

It is likely natural (pre-human) foredunes occupied by native sand-binding species (spinifex and pīngao), would have been ruptured or 'blown out' in storms due to high levels of sand accumulation or erosion (Wardle 1991). Large quantities of unvegetated sand combined with strong onshore winds would have formed parabolic dunes. The head of the dunes likely moved inland until there was insufficient sand to feed their movement. Behind the heads (and within the arms of the parabola) sand plains (or dune slacks) would have formed and these depressions may have filled with water. These 'dune slacks' often contain specialist short turf vegetation, succeeding into rush land. Resulting wetlands may then either be covered by subsequent sand movement or, where protected from further sand movement, develop into more stable scrubland and potentially even dune slack forest (Singers 1997) (Figure 8). 'Dune slack forest' was likely made up of predominantly kahikatea and pukatea. Apart from small reserves at Round Bush (~50 ha) and Himatangi Bush (~10 ha) almost no dune slack forest remains in the Foxton Ecological Region ecological district (Singers 1997). Wetlands could include 'dune lakes'; however, lakes would also have been formed by processes such as moving sands blocking streams (Department of Conservation 2002).

Most of these dunes and dune processes are now halted as planting of marram and non-native pines has reduced the formation of new dune plains and deflation basins along much of the coastline. Despite this, wandering parabolic dunes are still a potential threat to production forestry and some pastures. Ironically, marram can also lead to increased instability where it is growing on the foredune (Tawhirihoe Scientific Reserve site visit notes, DOC; Graeme La Cock, pers. comm.). The last, largely unmodified area of dunes (152 ha) runs inland 800 m south of the Rangitikei river mouth. The area, now called the Tawhirihoe Scientific Reserve, was obtained by the Department of Conservation in 2001. The dune slack wetlands, sand plains, fore-dune and rear-dune communities are of regional significance (Ravine 1992; Singers 1997).[22] There is no native forest or shrubland in the reserve, although it contains wilding pines and is bordered by extensive plantation forests.

[22] https://www.doc.govt.nz/get-involved/have-your-say/all-consultations/2016/wellington-cms/draft-wellington-cms/part-2/coastal-dunes-place/

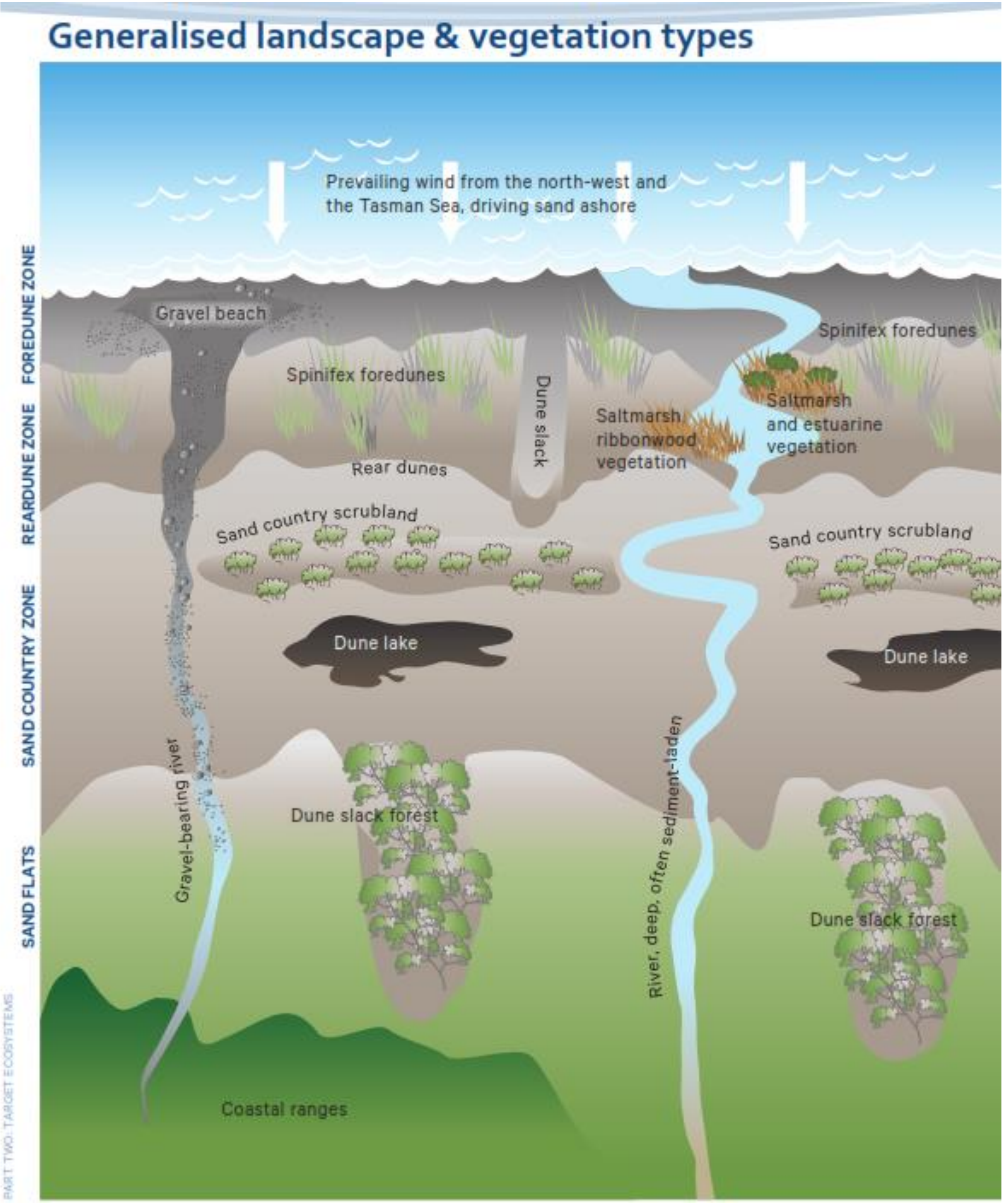

Figure 8. Generalised landscape and vegetation types within duneland systems based on the area of interest in this report (Wild for Taranaki 2018). The vertical scale is non-linear, progressing from meters at the top to kilometres at the bottom.

Ship Creek, South Westland is one of the few places to observe semi-natural progression of vegetation from foredune to reardune that includes forested areas, on a similar coastline (https://www.coastalrestorationtrust.org.nz/dune-restoration/plants-animals/) (Figure 9), although it is likely the progression from foredune to forest has been truncated at Ship Creek by past disturbance (Jill Rapson & Martin Sykes, pers. comms). Foredunes at Tangimoana would likely be larger, given it is a higher energy coast with more progradation (Rapson. pers. comm.), and the pre-human Foxtangi coastline would also not have been as lush given a significantly- lower annual rainfall than Ship Creek (La Cock, pers. comm.).

Figure 9. Ship Creek foredune to forest progression.

5.3 Existing biodiversity

Within Tangimoana Forest, the 250-ha coastal shelter belt of retained plantation forest is mostly 35-year-old radiata pine with some other much older (~100 years) non-native pine species present, probably maritime pine (*P. pinaster*). This coastal shelter belt is nearly-continuous and varies in width from 30 to 300 m (Figure 3). It has been claimed as 'retained forest' under the Forest Stewardship Council guidelines by Ernslaw One Ltd to be managed to restore *to a natural forest cover* (Forest Stewardship Council 2013), or if newly drafted guidelines are adopted, *to more natural conditions* (Forest Stewardship Council 2018). The latter option would allow creation of natural, non-forest habitats such as dune wetland/swampland and scrubland (Ravine 1992; Hesp 2001) and has potential to significantly enhance native biodiversity in this depleted area where only small pockets, and scattered individuals, of native plants currently exist. These include epiphytic ferns (*Asplenium* spp.) (Figure 10), the ground cover Native spinach (*Tetragonia* sp.) (Figure 11), divaricating coprosmas, mānuka, flax, toetoe, and cabbage trees. The creation of dune slack wetland habitats with both native and non-native turf, rushland and scrubland species in open dunelands is already well documented within the adjacent Tawhirihoe

Scientific Reserve, (Singers 1997; Hesp 2001; Rapson et al. 2016; Rapson 2018; Murphy et al. 2019).

Figure 10. At least four native fern species grow within the older areas of the retained plantation forest at Tangimoana, the most common are hanging spleenwort (shown), leather-leaf fern*,* shining spleenwort*,* sickle spleenwort, and bracken.

Figure 11. Native spinach (*Tetragonia tetragonoides*) groundcover under the edge of the retained plantation forest.

Less is known about the indigenous fauna within Tawhirihoe Scientific Reserve and the surrounding area, but the district would once have supported a diverse fauna due to its mild climate and mosaic of different habitats (Ravine 1992). The most conspicuous survivors are mobile native birds, including waterfowl supported by remaining dune lakes, habitat managed for duck shooting, and other wetlands (Ravine 1992). Bitterns, spoonbills, harrier hawks, black billed seagulls, black backed seagulls, and black shags are all found in and/or around Tangimoana forest, along with small forest birds (fantails, silver eyes, P. Horton, pers. comm.). Tangimoana Forest has also been identified as habitat for the New Zealand Falcon (Ernslaw One Ltd 2018-19). The nearby Pukepuke Lagoon supports species that are now rare in the region, including fernbird, spotless crake, marsh crake, NZ shoveller, and scaup.

Brockie (1957) described invertebrates found within three zones he classified as having 'sparse cover' nearest the sea, and 'more consolidated sand dunes' and 'grassed dunes' further inland. Moths, flies, and beetles were most common, and dragonflies and locusts were evident. At the time of survey, the coastline would have been severely degraded (and marram grass common), so this survey would not represent pre-human invertebrate assemblages. The endemic katipō spider is locally common (Ward 1998) and the rare moth (*Ericodesma aerodana*), whose caterpillar feeds on sand daphne, was found for the first time in 111 years by Ogle and Patrick in 1991. It is possible other insects and spiders in the region remain undescribed (Ravine 1992). Anecdotally, huhu beetles are numerous, feeding on large amounts of deadwood generated through forest management (thinning), and felling (P. McCarthy, pers. comm.).

There are no records of native amphibians and reptiles in the reserve although gold-striped geckos, common geckos and common skinks are just outside the region (Ravine 1992; Department of Conservation 2007). Adjacent wetlands such as Pukepuke lagoon contain freshwater native fish including the at-risk/declining Kowarō or brown mudfish and inanga.[23] This lake, along with others, and their associated outlets, have in the past also been important tuna or eel fisheries (Wildlands 2017, https://www.romst.co.nz/pukepuke-lagoon-conservation-area.html).

5.4 Potential biodiversity opportunities

To maximize biodiversity gains within plantation forestry landscapes in general, we identified natural habitats that are locally under-represented as these habitats could offer the greatest potential biodiversity value for restoration (Horizons Regional Council 2014).[24] Several wetland and duneland habitats are classified as 'rare' within our study area (the most critical habitat type). Effective restoration requires significant planning, one-off establishment inputs, and long-term maintenance, particularly for pest plant and animal control. An advantage of restoring areas adjacent to production forestry blocks is that earth-working and forest-felling machinery is available for initial restoration works. These machines, normally used to create skid-sites, processing areas, roads, and fire-fighting

[23] Shand R 2017. Geomorphological assessment and management considerations for the Pukepuke lagoon natural heritage restoration project. A report prepared for Department of Conservation https://ref.coastalrestorationtrust.org.nz/site/assets/files/8211/draft_pukepuke_geormorphological_assessment_-_doc-3162695.pdf.

[24] The method developed within the One Plan to identify and assess ecologically significant habitats is based on relatively rigorous criteria as demonstrated in a study by Maseyk and Gerbeaux (2014).

ponds could also be used to create dune wetland features and small clearings. Forest companies also have weed and pest control experience and such operators could potentially extend operations into restored areas at marginal additional costs with suitable training. A disadvantage of establishing restoration areas adjacent to production forests is that road access and machinery also provide a source of invasive weeds.

Some native plants species of sand dune wetlands, especially ephemeral wetlands in dune slacks, have propagules that are widely dispersed by wind, water or animals (e.g. waterfowl), and can spread rapidly under suitable conditions, while others must be deliberately introduced (Murphy et al. 2019). The low-fertility conditions typical of these raw dunes and areas without introduced legumes (like broom, gorse, and lotus) may help reduce competition from common non-native plants, particularly pasture grasses (Bird & Choi 2017; Kooijman et al. 2017), although Murphy et al. (2019) identify browntop and Yorkshire fog as important competitors in their study of created wetlands within Tawhirihoe Reserve. Sources of propagules for some shrub and tree native plant species are absent or sparse, and existing animal browsers (especially from deer but also rabbits) will restrict natural regeneration to unpalatable species in accessible areas. Enhancing native habitats for biodiversity gains at Tangimoana will therefore likely require some re-introduction of specific native plant species alongside ongoing control and exclusion of specific plant and animal pest species.

The retained plantation forest already supports some biodiversity values indirectly by forming a physical barrier that buffers the inland spread of highly invasive coastal species such as acacia and pink ragwort. A further opportunity provided by retained plantation forest is provision of shelter and stability, providing suitable conditions for dune slack forest canopy species or species that would usually require more stable inland water features, such as lakes and swamps.

We explore four options to enhance indigenous biodiversity within the existing plantation forest at Tangimoana, and in the adjacent area including within the Tawhirihoe Scientific Reserve and Pukepuke lagoon:

- creating pockets of dune habitats within retained plantation forest, including wetlands/swamps, lakes, scrublands and forests
- creating a new ecological corridor from Pukepuke lagoon to the coast
- harvesting options that enhance biodiversity, and
- enhancing the adjacent Tawhirihoe Scientific Reserve.

5.4.1 Creating pockets of dune habitats within retained plantation forest

The biodiversity values associated with the 250-ha strip of retained plantation forest running adjacent to the coastline within Tangimoana Forest could be enhanced using a range of restoration activities. These activities range in intensity, from enhancing existing regeneration by targeted canopy opening, exposing bare soil, and exclusion of browsers to active land contouring, planting, seeding and pest control. The retained forest is the primary focus for this approach, as this means enhancement actions do not remove productive forest operations and could be sustained for many years.

Given existing retained plantation forest will eventually start to open up as older trees die, the long-term future of this strip needs to be considered now. Although its primary function is to protect adjacent productive forest, the introduction of complementary indigenous vegetation could maintain protection and provide additional values. This approach is most feasible where the retained plantation forest is particularly wide (200–300 m) and where foredunes are stable or can be stabilized without pine trees or invasive acacia. Foredune stabilisation using native sand-binding species that produce lower dunes (reducing the risk of sand inundation) is being developed and trialled locally.

A mosaic of mid- to late-successional, rare[25] dune habitats, such as sand dune wetlands/swamps, scrublands and forests could be established within the retained plantation coastal forest. Emergent tree species have the highest risk, especially close to the coast, as it is uncertain how close dune slack forests grew to the Foxtangi coastline in pre-human conditions. If native tree species are a high priority, a lower-risk restoration approach is Option 2 (see section 5.4.2), linking the coast with Pukepuke lagoon, as these forests are further from the coast. Restoration methods should be trialled and developed on small patches within the leeward edge of the retained plantation forest where the risk of dune blow-outs is low. High-priority target areas would be naturally damp hollows within the retained plantation forest where non-native pine trees have either failed to establish, are weak, and/or or have fallen over. Some of these areas already support native plants, and, depending on water table depth, may be conducive to wetland/swampland, scrubland and swamp forest restoration. Pine trees in these areas would be thinned by ringbarking, or drilling with herbicide, or felling. Research in Marlborough suggests gaps need to match light requirements of regenerating or planted species, and generally no larger than the height of the canopy (Forbes 2015).

A combination of tree killing methods should be trialled; felling either live or pre-killed trees creates the opportunity to use branches to reduce animal access to planted or regenerating native plants. Trials could include combinations of canopy manipulation to increase ground light levels and water availability, earthworks/clearance methods and introduction of indigenous species with weed and pest control. Some earthworks may be beneficial and could include removing the pine needle thatch and exposing bare soil to assist seed regeneration where there is no seed bank of broom, gorse or acacia. Earthworks may also be required to expose summer water table. Recommendations for restoring habitats by planting native species that best suit site conditions are detailed in 'Restoration planting on the coast from Hawera to Paekākāriki: A guide to the Foxton Ecological District' (2018 Wild for Taranaki).[26] A generalized landscape and vegetation type diagram with the current scenario overlaid in green is shown in Figure 12, followed by a hypothetical arrangement of wetlands/swamps/lakes, scrubland and forest within or behind the current retained plantation forest in green (Figure 13).[27]

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[25] As defined in Schedule-F (Horizons Regional Council 2014).

[26] https://www.restoretaranaki.nz/wp-content/uploads/2019/06/Wild-for-Taranaki_Restoration-Planting-Guide_Foxton.pdf

[27] Pre-human conditions along this coastline cannot be *re*-created. The area available for natural dunes processes to occur is relatively small with pressure from all directions, including sea level rise, although this

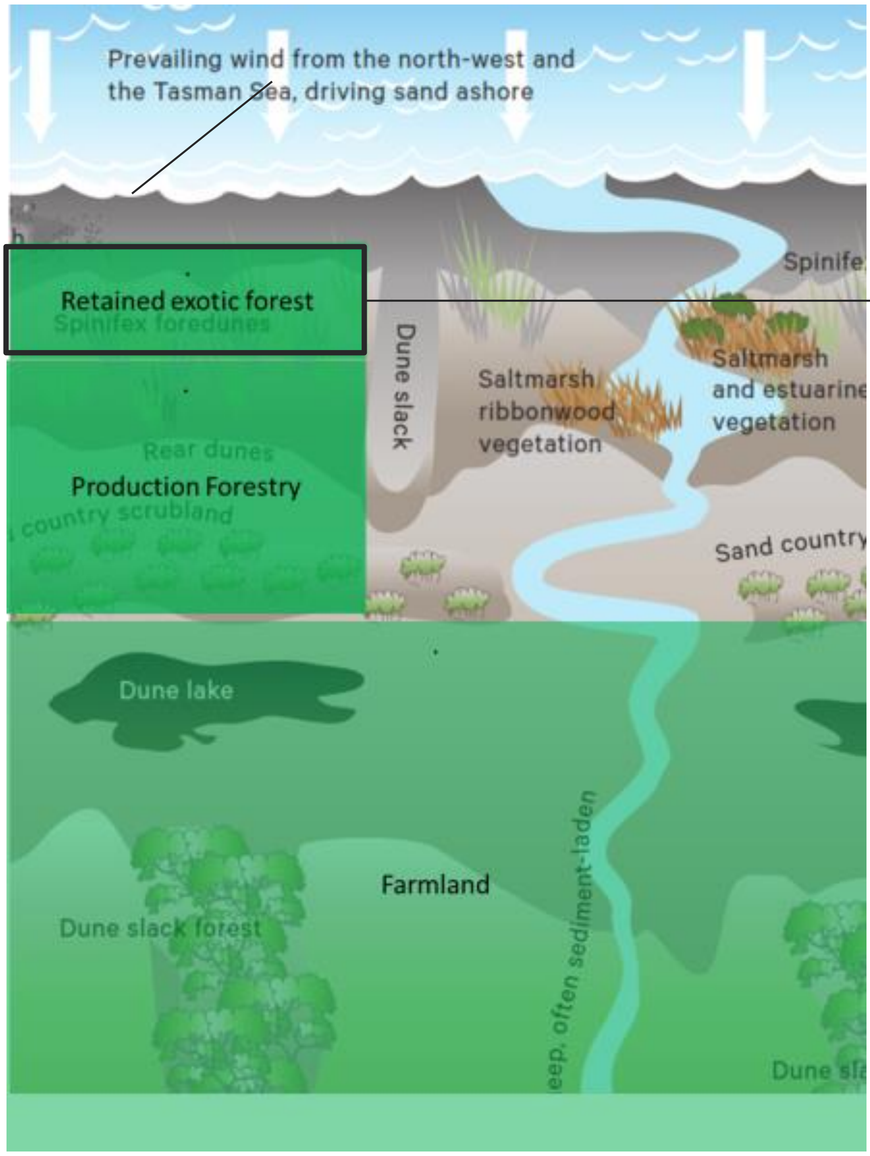

Figure 12. From Wild for Taranaki (2018) showing position of farmland, production plantation forest and retained plantation forest overlaid on the generalized landscape & vegetation type (diagram from Fig. 8).

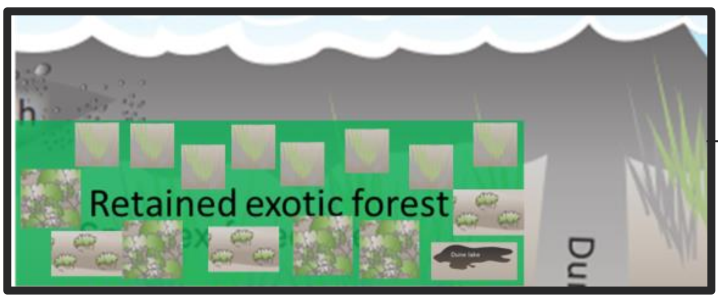

Figure 13. Hypothetical arrangements of dune slack swamps/lakes, scrubland, and possibly forest within and/or behind the retained plantation forest at Tangimoana Forest.

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coastline is prograding (Gibb 1978; Murphy et al. 2019). Non-native species will always be a component of the environment and their ongoing management needs to be included in strategic planning.

Wetlands/swamps/lakes

The recommended priority for rapidly and cost-effectively enhancing biodiversity values is to kill and/or carefully remove pockets of selected pines to increase ground-level light and help restore water levels where native plants have established. Target areas include wilding and planted pines in and around moist low-lying ephemeral or permanent wetlands (Figure 14). Killing pines first will reduce damage to undergrowth if trees are removed to the edges of such areas. Retaining dead slash/branches at the edges of such areas could help to provide physical protection from deer browse, allowing natural establishment of palatable native seedlings. Trees near edges can also be pushed over (or cut down) towards 'uphill' edges so that the resulting elevated root plate forms a habitat structure. Such areas could be further enhanced by planting species that will not naturally establish because seed sources are too distant (e.g. flax and some heavy-seeded rushes). Protecting biodiversity at these sites will also require managing the actual or potential risk of invasive weeds (especially acacia, pampas, gorse and broom – the latter is spreading along road edges) and pests, especially Sambar deer, possums, and rabbits.

'Pocket' wetland areas could also be developed by amending existing fire-fighting ponds. Most of these ponds are 'bathtubs'; at least 1.5 m deep, with steep sides. Recontouring of two sides to gentle slopes with some areas of very shallow inundation and very low slopes would allow these ponds to become a series of stepping stones with more diverse native wetland plant and invertebrate species (Figure 15).

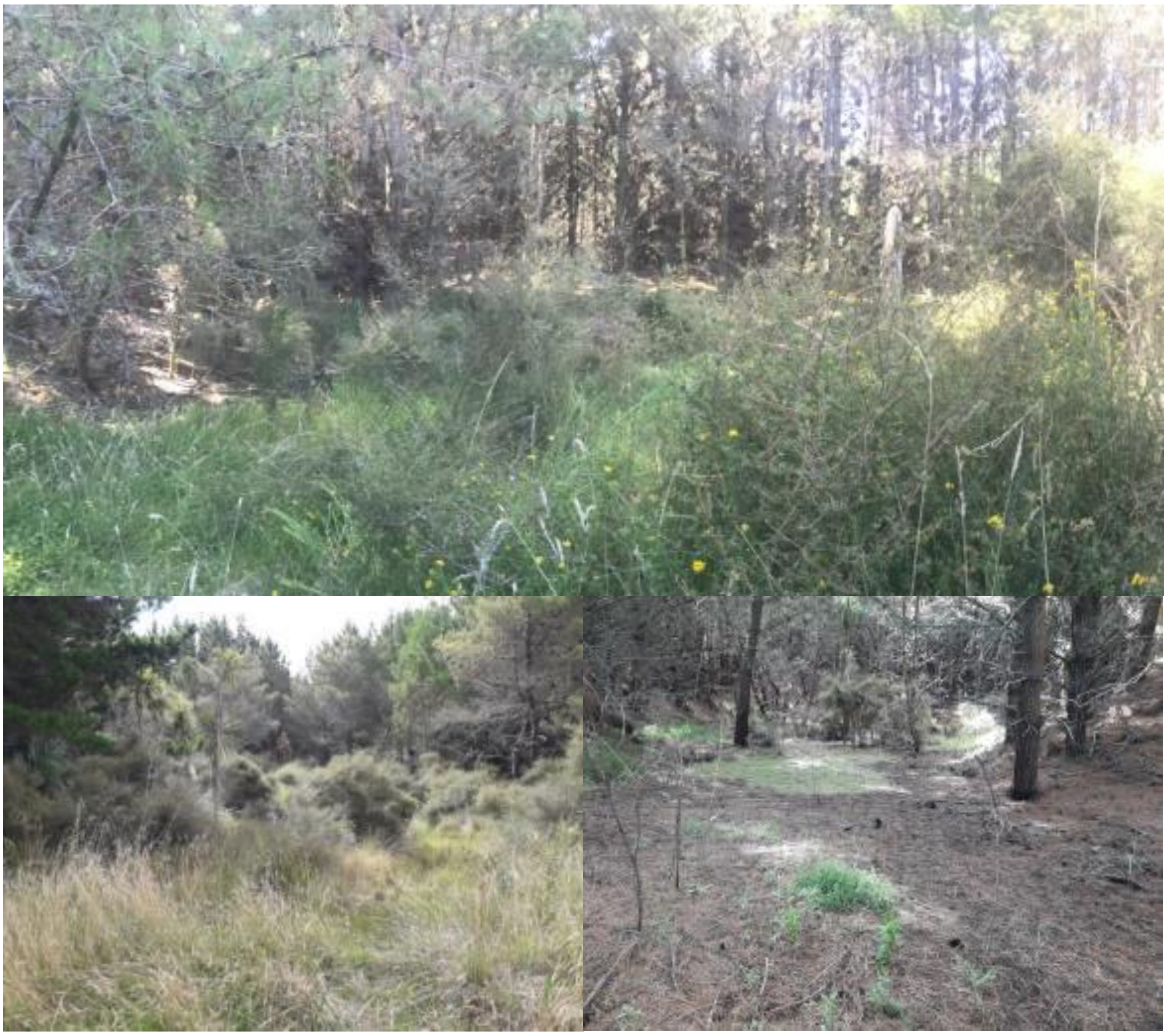

Figure 14. Wetland areas within the retained plantation forest with potential for rapid and low-cost restoration.

Figure 15. Example of a water supply pond with emergent raupō that could be recontoured on 2 or 3 sides and extended to enhance indigenous biodiversity values

On larger, non-forested, open areas, shallow scrapings to expose ephemeral water tables could deliver dune slack wetlands, using guidance from trials in Tawhirihoe Scientific Reserve. The trials indicate critical success factors include extremely shallow (1 percent) slopes and planting or seeding of some native species (Singers 1997; Rapson et al. 2016; Murphy et al. 2019). Further, new wetlands are most successful when within 1 km of adjacent existing wetland habitat (Rapson pers. comm.). Such wetlands are ideally planned sequentially so new 'scrapings' replace those that revert to rushland and shrubland through natural succession at about 10-year intervals (Murphy et al. 2019). Large, open areas for such treatments within Tangimoana forest could include places where harvesting takes place near the water table. Forestry earth-moving equipment could efficiently contour suitable slopes and water table depths. Compaction and topsoil removal (where present) related to skid site development means such areas often have higher pine mortality with poorer growth and form, so production losses from wetland creation could be minimal. Linking wetland creation with harvesting (and periodic renovation of fire-fighting ponds) would enable new wetlands to be created over time. Such connectivity in time and space enhances biodiversity by allowing native flora and fauna to naturally colonize new areas (Singers 1997).

However, even though Ernslaw One Ltd has consent from Horizons to reshape the dunes where required, Manawatu District Council (MDC) regulations may prevent this (James Sinclair, pers. comm.). MDC has scheduled this section of coast as an outstanding natural landscape (ONL) which includes most of the retention buffer. This comes with various restrictions on land management activities, especially earthworks- https://www.mdc.govt.nz/Contact-Us/Have-Your-Say/Previous-Consultation/Plan-Change-Consultation/Draft-Plan-Change-65-Natural-Features-Landscapes.

Scrublands

In places where natural clearings and/or native remnants occur, pine forest could be converted to dune scrubland vegetation by increasing light penetration (selective thinning/felling) and controlling invasive weeds and pests. The most cost-effective areas to target would not have invasive weeds such as acacia. Acacia, a very aggressive, light-requiring invader, often found in clearings, has been at Tangimoana for 50 years (Figure 16). Blackberry, gorse, pink ragwort, field horsetail, and boxthorn may prove to be just as invasive as acacia in future, despite being in the area for up to 30 years. Broom too, a more recent arrival, is of concern. Pro-active removal of these weeds, especially where outliers occur, is particularly important both to protect future biodiversity values and to minimise the enormous future costs that result from managing long-lived seed banks. Broom is often associated with production forestry (Potter et al. 2009) and has a very long-lived seedbank. It is just starting to appear along the sides of tracks within Tangimoana forest. As a nitrogen fixer, broom enriches soils and may help non-native grasses establish. Together, broom and exotic grasses could smother native dune-slack wetlands and scrublands. Preventing the spread of broom now, using herbicide application would be prudent and is likely to be cost effective, otherwise some promising new developments with the biological control of broom may help control dense areas of broom in future.[28] As with dune slack wetlands, some initial planting may be required to establish species that are rare or are no longer found in the area, for example sand spike sedge, matagouri, tutu, akeake, and kowhai. Sand daphne may also be a candidate but is a rear-of-foredune species that probably requires mobile sand (Rapson, pers. comm.).

Figure 16. Light gap with invasive acacia and native toetoe in flower.

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[28] The broom gall mite was imported into New Zealand in 2006 and is starting to have significant impacts in some areas of New Zealand
http://www.landcareresearch.co.nz/__data/assets/pdf_file/0018/20565/Broom_Gall_Mite_Dec_14.pdf,
https://www.landcareresearch.co.nz/publications/newsletters/biological-control-of-weeds/issue-75/broom-gall-mite-a-decade-on

Forests

As with indigenous scrubland creation, areas within retained plantation forest could also be managed to encourage indigenous tree species. Increasing light at ground level by killing pines in small, artificial canopy gaps could accelerate restoration. Locations should be carefully selected to build on areas where indigenous plants exist (or are planted and managed) and avoid areas vulnerable to invasion by non-native species like acacia, broom and pampas. Palatable plants (larger-leaved coprosmas, tutu, mahoe) will require protection from herbivores (Sambar deer, possums, and rabbits). Rabbit browse can be prevented by low-cost individual plant excluders or medium-term application of repellants. Where long grass is present, planting tall native seedlings (in autumn) without spot spraying is another technique that can reduce rabbit browse, and would suit damper sites where drought competition is not severe. Pine slash may be used to exclude herbivores, but the effectiveness of this method for Sambar deer needs to be tested (Figure 17). In some cases, epiphytic plants (e.g. broadleaf) could be established on pine stumps cut above deer browse height, as has been done with rātā at Keebles bush, near Palmerston North. This could be achieved by cutting mal-formed trees with negligible timber value at 2–2.5+ m height, and ideally above a whorl. Pine slash also has value in creating sheltered microsites, and as habitat for native decomposers, i.e. huhu beetles. Biodiversity benefits from creating pockets of native forest and shrubland habitat are enhanced when cats, rats, stoats, weasels, ferrets, and hedgehogs are controlled, as these predators impact most native birds, reptiles (if they can be re-established) and some insects. A lack of nearby native bush remnants (Figure 4) means some native animal and plant species may fail to re-colonize without assistance. Mature indigenous (and non-native) trees will ultimately provide the habitat complexity required to attract a wider range of indigenous fauna (Peterson & Hayman 2018) and promote low light, low nutrient conditions favourable to native plant species at the expense of high light and/or high nutrient dependant, invasive species like acacia, broom, and non-native grasses (Figure 18).

Figure 17. Naturally wind-thrown pine tree in small wetland area creating habitat complexity; the head (branches) may help protect native re-growth from sambar deer browse.

Figure 18. Invasive acacia seedlings in a light gap within the retained plantation forest with compromised canopy (left) and near the coast (looking east).

5.4.2 Pukepuke lagoon to the coast ecological corridor

A long-term biodiversity-enhancement opportunity would be creating a 160-ha corridor from Pukepuke lagoon to the coast (Figure 19). Despite major hurdles of compensation for lost plantation production, widespread consultation, (Sinclair, pers. comm.) and establishment costs, the potential landscape-scale biodiversity benefits and linked cultural benefits this option could deliver means it is worth exploring. The process of establishing the corridor would involve gradually replacing currently productive plantation forest and pasture with native species, alongside the Pukepuke outlet, using techniques identified in the previous section (5.4.1).

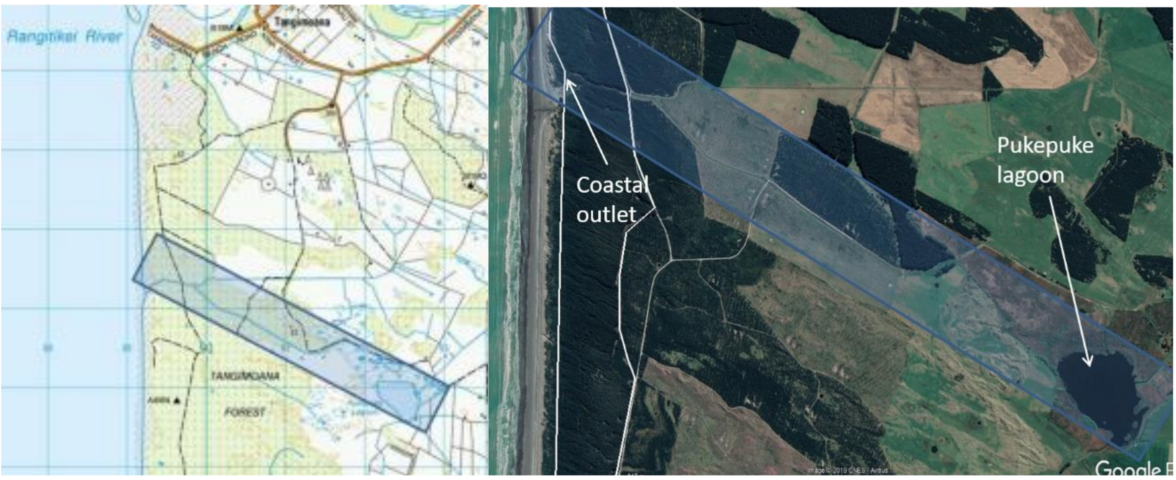

Figure 19. Proposed 160-ha restoration area from Pukepuke lagoon to the coast.

A restoration programme is currently underway at Pukepuke lagoon (Wildlands 2017 draft document). Adding an ecological corridor to the coastal outlet of the lagoon could connect a range of successional stages from active dune through to coastal swamp forest. Although the current lagoon outflow may be a post-European artifact (Rapson, pers. comm.), it nevertheless provides an opportunity to connect habitats supporting a range of both terrestrial and aquatic flora and fauna, i.e. for migration of diadromous eels and galaxiids (whitebait) (Department of Conservation 2007; Wildlands 2017). This restoration option is the only approach that would provide a corridor to connect foredune to reardune habitats that includes an area where we are confident viable dune slack/coastal swamp forest was present in the recent past. Appendix 4 shows photos along the Pukepuke outlet as it currently exists.

Nearby Omarapapaku (Round Bush Reserve) provides a template for the floral and faunal communities. The reserve, approximately 5 km inland and 4 km NE of the Foxton port, is one of the last remaining coastal swamp forest remnants in the area (Figure 20). Mature indigenous forest existed in 1914 and probably looked similar (except for the milled edge) to those below (Figure 21), but by 1918 most emergent kahikatea had been harvested (Esler & Greenwood 1968) and few remain today.

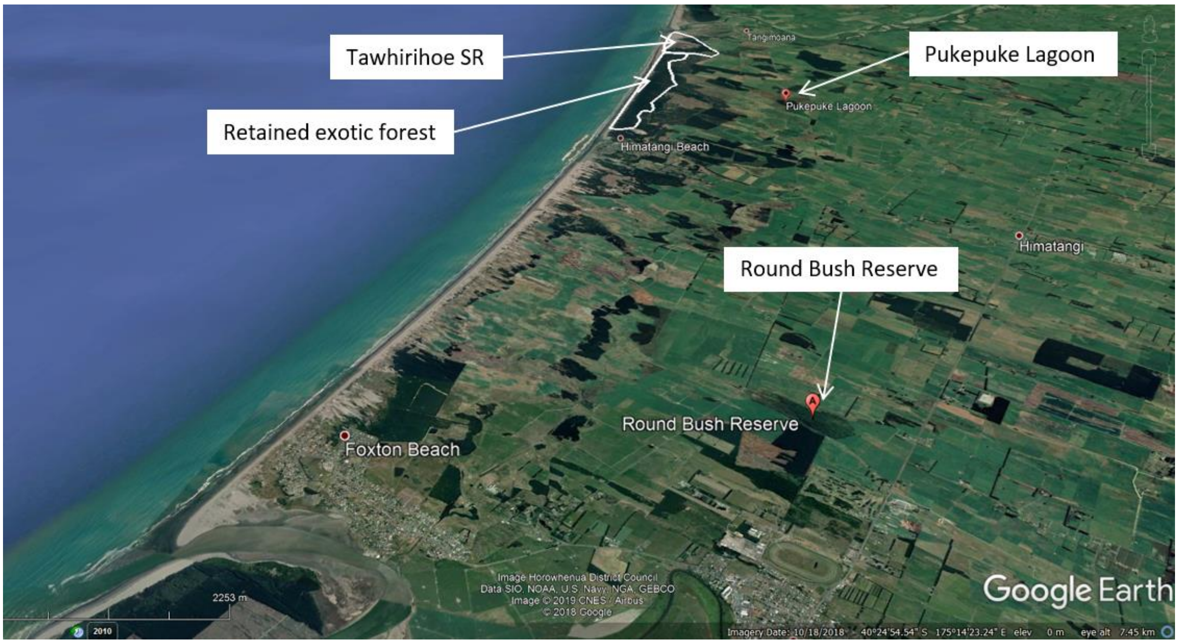

Figure 20. Location of Round bush reserve in relation to retained plantation forest at Tangimoana and Tawhirihoe Scientific reserve.

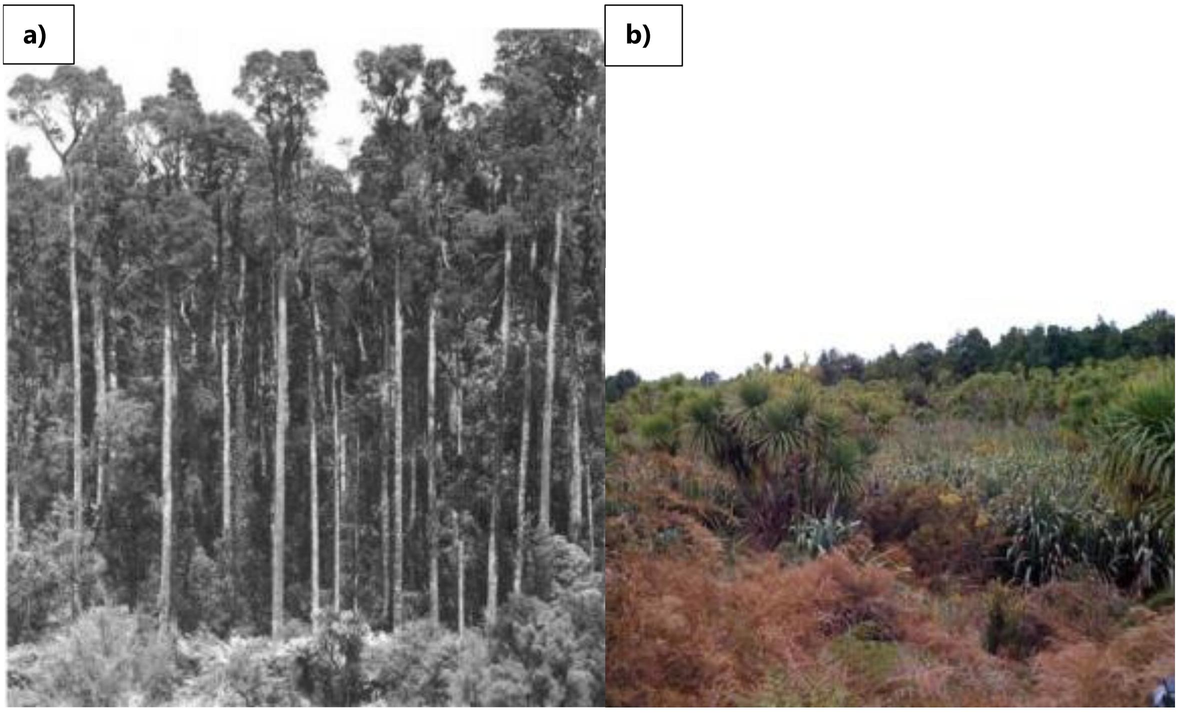

Figure 21. a) How Omarupapaku may have looked in 1914 before harvest. Harihari, West Coast, South Island (Photo: J. H. Johns); and b) Round Bush Reserve today – the emergent canopy is almost all gone.[29]

[29] https://envirohistorynz.com/2011/12/25/omarupapaku-old-mother-parker-the-forest-that-was/

5.4.3 Harvest options that enhance biodiversity

There are limited opportunities for native biodiversity to develop within areas of productive plantation forest because of periodic clear-felling, although species that quickly recolonize areas (i.e. ferns, rushes) or those with large home ranges (New Zealand Falcons) may benefit. The following practices would help limit inadvertent loss of native biodiversity linked with clear felling, due either to removal of features that indigenous flora and fauna were exploiting (i.e. habitat complexity, dead wood, protection from wind, sun and salt spray) or to invasion of competing weeds:

- ensure harvesting and earth-working machinery is free of weeds and soil before entering sites (new weeds are appearing and spreading in Tangimoana forest, i.e. field horsetail spreads in damp areas and broom along forestry roads) and ensure any road gravels or straw used are weed free
- identify, monitor and control activities that may encourage invasive species so areas of rotational forestry are not reservoirs of weed and pest species
- identify native animal species that cannot move to adjacent forest blocks and provide 'escape routes'[30] or active management like translocation
- consider ecological outcomes when locating skid sites/processing sites, fire-fighting ponds and roads
- identify areas with high water tables, where post-processing earthworks could easily create wetlands by ponds
- relocate some roads and access tracks away from vulnerable areas managed for biodiversity values (such as wetlands) to provide a buffer against movement of weeds and pests and reduce the damage caused by off-road vehicles and degradation of water quality, and
- leave any native understorey vegetation (e.g. cabbage trees, ferns, coprosmas, rushes) on the margins of drains, roads and stands to help their natural dispersal into adjacent newly disturbed and/or planted areas.

5.4.4 Tawhirihoe Scientific Reserve

Forest Stewardship Council guidelines allow for 'equivalent ecological effort' by Ernslaw One within the district or region if work within the Tangimoana forest management unit is not possible (Forest Stewardship Council 2013). The adjacent Tawhirihoe Scientific Reserve includes active dunes and dune slack wetlands which are rapidly becoming shrublands (Figure 22). The reserve may not be large enough to allow natural dynamic processes to continue indefinitely which will prevent a full range of habitats developing (Rapson, pers. comm.; Department of Conservation 2007). However, artificial dune slack wetland creation has been trialed in the past and could be continued to support early successional native wetland species. Additional work could also help to create viable reardune habitats such as

[30] There is value in escape routes for kiwi (Sporle 2016, https://rarespecies.nzfoa.org.nz/species/great-spotted-kiwi/) and it is likely that some other faunal species would benefit from a similar approach, although it is not clear if any currently exist in Tangimoana Forest.

additional dune slack scrublands and forests. The forestry company has the required expertise and large machinery to effectively contribute to tree killing/felling/placement and earthworks. The value of Tawhirihoe Scientific Reserve could be enhanced by transitioning areas of non-native pines on the edge of the reserve, like Fern Bird Flat (Figure 23).

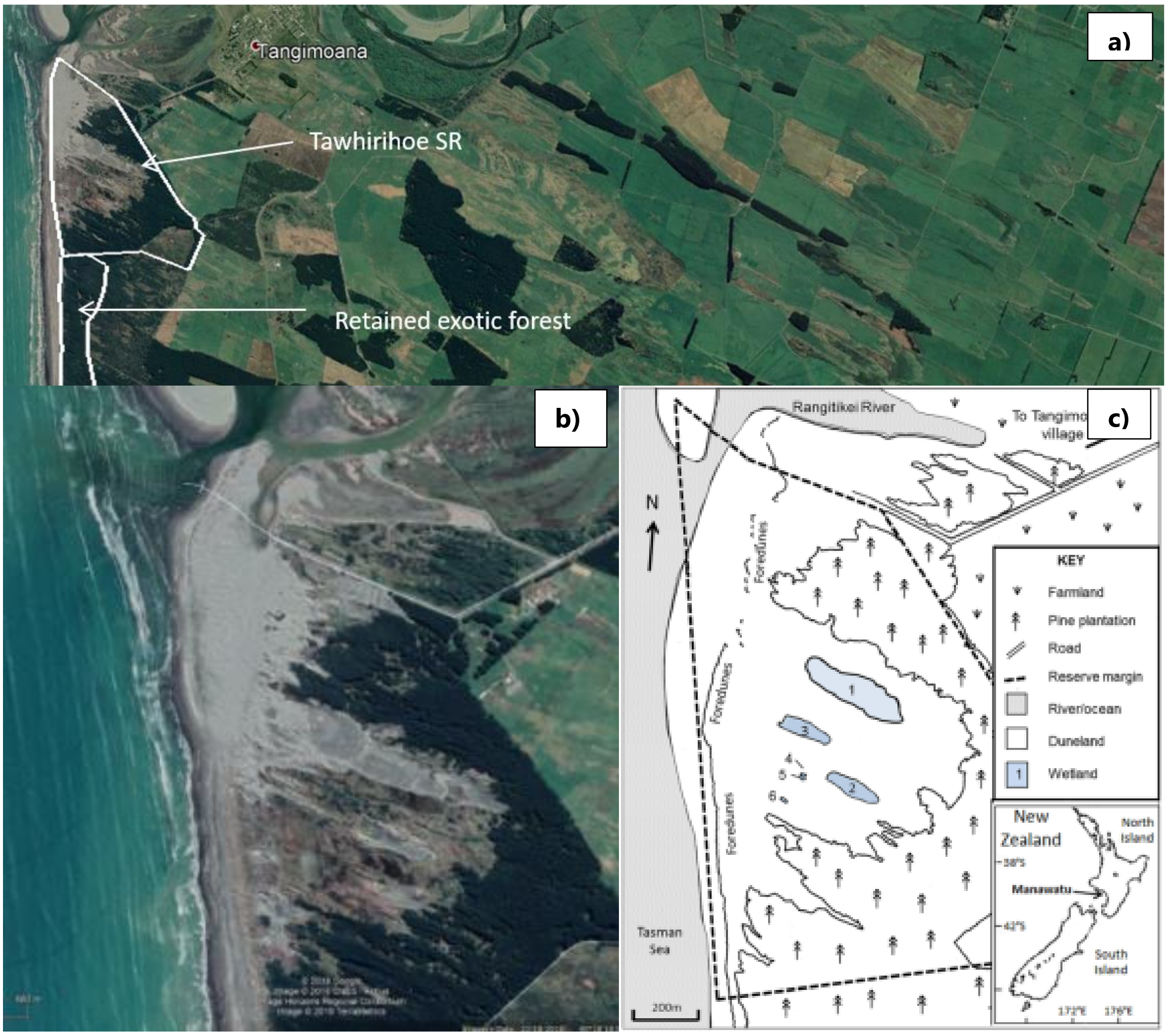

Figure 22. a) Tawhirihoe Scientific Reserve b) image of the reserve at a finer scale) and c) the reserve wetland areas (Murphy et al. 2019).

The Tawhirihoe Scientific Reserve management strategy (Department of Conservation 2007) suggests restricting vehicle access, weed control, enhancing indigenous flora and fauna, and managing dune stability. Relocating access roads away from sensitive areas and closer to reserve boundaries and installing physical barriers to vehicle access such as ditch/log barriers[31] would not only help protect areas from physical damage, but are also likely to slow the invasion of new weed species, especially those that are in adjacent areas. The Department of Conservation is currently managing pampas, field horsetail, blackberry,

[31] Gates and locks are generally not effective

pink ragwort, Japanese honeysuckle, and boxthorn in the reserve (Samantha Gale, pers. comm.), recognizing this is a long-term commitment. Logs from felled pines can also be used to enhance dune stability. Fencing is not required as grazing pressure is minor in the reserve.

Future DOC management of areas of non-native pines within the reserve could include a variety of thinning methods to optimise biodiversity values (as described in Section 5.3.1). Priority wetland earthworks in Fernbird flat would be to relocate or infill old drainage channels. Facilitating succession to indigenous scrubland and forest along inland boundaries is likely to be important to maintain the barrier to future inland migration of sand dunes as is achieving the cooperation of neighbours.

Figure 23. Fernbird flat is at the rear of the Tawhirihoe Scientific Reserve's boundary adjacent to the retained plantation forest.

5.4.5 Costing comparison

The cost of current ecological work done in New Zealand by Ernslaw One Ltd, and those of proposed options for Tangimoana Forest is shown in Table 3.

Table 3. Current ecological work undertaken by Ernslaw One Ltd throughout NZ and proposed options for Tangimoana forest – a cost comparison

Options	Activity	Indigenous biodiversity benefits	Management and production implications[32]	Costs	Ranking of future options
Current work likely to benefit indigenous biodiversity within Ernslaw One Ltd forestry landscapes in NZ. **70,000-ha**	Plant pest control. Pre-planting, roadside and boundary control of plant pests.	Reduces weed spread within and from production management units especially if population outliers are identified and removed to prevent spread.	Maximises pine seedling survival, establishment and early growth. Complies with Regional Pest Plant Strategies, may reduce post-planting herbicides.	Approximately $1.33/ha/yr = $93,100/yr. Average across all 70,000-ha of productive plantations but a) uneven spread across forests in any one year and b) does not include identification and control of 'ecological' weeds.	**Total ongoing cost estimate** **$8.13 – $208.13/ha/yr ($569K – $14.6M) + $15K/ha for restoration planting.** Upper limit is exaggerated. Much of the retained area is probably not suitable for production or has low production, so would not attract the same lost opportunity cost. Also, restoration planting is often limited to relatively small areas, especially where natural regeneration is present and can be enhanced.
	Animal pest control. Possum control ongoing through regional council toxin programme. Sambar deer managed through hunting permits as a resource.	Benefits native birds, reptiles, invertebrates Deer are not generally controlled to a level that allows palatable vegetation to regenerate.	Crop protection. Managing sambar deer control through recreational hunting may not result in very low populations	Approximately $3.23/ha/yr = $226,100/yr. Average across all 70,000-ha of productive plantations but uneven spread across forests in any one year.	
	Ecological surveys	Information about habitats/species that need protecting.	Access to forests for survey. Potential restriction of production activities, wildlife permits may be needed	Approximately $0.71/ha/yr = $50,000/yr uneven spread across forests and species in any one year. Excludes University studies?	
	Managing rare threatened and endangered (RTE) species, e.g., Brown mudfish, NZ falcon, *Powelliphanta* snails (Santoft & Shannon). Kiwi, blue duck and long-tailed bats (Waimarino forest).	Maintenance of habitats, range, population abundance and diversity when management is successful.	Native areas are assessed and classified as reserves with no clearing of existing indigenous vegetation. Within production areas RTE species management plans outline procedures when operations encounter them. This may include active management, e.g. if a NZ falcon nest is found operations are stopped, moved, and a predator trap network set up around the boundary of the nesting site for mustelids, cats and possums.	Approximately $2.86/ha/yr = $200,200. The costs for each RTE species vary. Some have no costs (e.g. mudfish as wetlands and buffers are avoided, although planting is additional). Species requiring pest control are more costly (e.g. $70K/year spend on two kiwi recovery projects); moving harvesting contractors when a NZ falcon nest is encountered usually costs $15–20K.	

[32] The health and safety of operators will have management and production implications for all activities listed.

Options	Activity	Indigenous biodiversity benefits	Management and production implications[32]	Costs	Ranking of future options
Current work likely to benefit indigenous biodiversity within Ernslaw One Ltd forestry landscapes in NZ. (cont.)	Retained plantation forest includes areas that could otherwise be used for productive plantations but cannot for environmental reasons (including NES-PF requirements) + restoration work, and also areas that are too dangerous to harvest.	Create or improve indigenous habitat	Main costs associated with loss of productive forest and/or future opportunity costs. Limitations on forest access and potential constraints on harvesting operations. Where forests are uneconomic or unsafe to harvest, costs may be negligible, unless wilding pine control is required.	Very difficult to estimate[33]. Lost opportunity cost for setting aside/retaining areas is approximately $2K/ha/yr. Assuming a 10% retention on 70,000-ha opportunity cost is = $14M, or, as a cost per ha of the total management unit $14M/70,000-ha = $200/ha/yr. Cost to restore retained areas if using planting is approximately $15K/ha ($6/plant at 2m spacing).	(see above)
	Riparian, wetland, and lake management	Protects aquatic habitats and waterways including downstream water quality by decreasing sediment, nutrient and debris loads. Provides habitat for semi-aquatic organisms.	Lost production area. Management considerations when working around riparian strips to prevent runoff and physical damage from operations while harvesting.	No estimate available. Costs associated with managing operations close to riparian strips are difficult to estimate. They are very dependent on terrain (i.e. ground based versus hauler operation). In the Rangitikei Sands forests there are no additional costs because the logging is ground-based on flat terrain. Mechanised felling is done away from streams.	

[33] Areas are not always set aside for environmental reasons. Sometimes areas are too dangerous to plant or are unsuitable/marginal for tree growth (swamps) or are used as shelterbelts. Also, areas of high risk are usually not replanted but allowed to revert naturally. Control of wilding pines in retired areas is the biggest challenge/cost.

Options	Activity	Indigenous biodiversity benefits	Management and production implications[32]	Costs	Ranking of future options
Option 1. Develop pockets of indigenous dune/dune slack habitat within existing retained plantation forest (250 ha)	Native planting or other interventions that complement natural regeneration including vulnerable wetland/duneland species.	Benefits biodiversity by speeding up regeneration and introducing species that can't/or may be very slow to regeneration naturally.	Some species could restrict access, e.g. matagouri or muehlenbeckia	A maximum of $15K/ha if planting at 2-m spacing. Some interventions could be done by Massey students as part of a teaching programme or volunteer groups, e.g. removing pine needle litter.	Ranking: 1 Good medium to longer-term biodiversity benefits, low management and tree production implications, low cost especially where regeneration is accelerated. Challenges associated with pest plant and animal control. Tangimoana forest is leasehold land and therefore any land use changes would need to be led by the landowner (Rangitāne o Manawatū). This also applies to option 2.
	Plant pest control.	Facilitates native regeneration. Reduces weed seed banks.	N/A	Approximately $1.33/ha/year = $332/year. To be effective needs to include removal of outliers, prevention of weed breakthrough from the coast (espec. acacia) and identification and removal of new environmental weeds as well as 'production' weeds	
	Animal pest control.	If sustained, benefits native birds, amphibians, reptiles, invertebrates and palatable vegetation.	N/A	Approximately $3.23/ha/year = $808/year but this does not include hedgehogs, rats or sambar deer.	
	Poison and/or fell non-native trees in and adjacent to summer-moist areas with high water tables.	Raise water table and reduce shading to providing habitat for wetland species and leave fallen trees and stumps in place for habitat complexity.	To be done when machinery is on-site for other operations.	Approximately $75/hr for manual felling and $300/hr for a felling machine = $525-$2100 for a day's work (use $4,200 for one-off 2-day cost estimate).	**Cost in 1st year is $7,861 (tree felling, pond conversion, weed pest control) + $15K/ha for restoration planting. Ongoing cost is $4.56/ha/yr.**
	Conversion of decommissioned fire ponds to ponds with shallow sides at minimum 1 km spacing.	Stepping-stones for wetland and ephemeral plant and animal species.	To be done when machinery is on-site for other operations.	Approximately $180/hr. Assuming this can be done under MDC regulations = $1,260 for a day's work (use $2,520 for one-off 2-day cost estimate – more required after 10 years).	
	Development of coastal foredune by planting.	Expansion of indigenous habitat.	Helps stabilise sands in lower dunes less prone to break out where native spinifex is a dominant component.	Approximately $15K/ha.	

Options	Activity	Indigenous biodiversity benefits	Management and production implications[32]	Costs	Ranking of future options
Option 2. Create an indigenous corridor from Pukepuke lagoon to the coast (160 ha)	Create a corridor from the coast to Pukepuke lagoon on either side of existing waterway/drainage channel.	Creates an area that can be developed to connect coast to inland habitat for both aquatic and terrestrial indigenous species.	Productive forest removed and/or future opportunity costs. Limitations on forest access and potential constraints on harvesting operations. The corridor would likely divide the forest.	Large lost opportunity cost as pines can be worth $250K/ha at maturity. Lost opportunity cost is $2K/ha/year if restoration starts after felling in 23 years-time (assuming a 30-year rotation).	Ranking: 2 Very good longer-term ecological benefits but significant challenges associated with plant and animal pest control. More importantly, tree production implications would be significant, and a detailed cost-benefit analysis would be required as a starting point. Compensation, consultation, and management implications would all be major hurdles. **Cost in 1st year assuming a start time after harvesting is $2,004.56/ha/yr ~$320,730 (opportunity cost +weed and pest control) + $15K/ha for restoration planting. Ongoing cost is $2,004.56/ha/yr.**
	Restore to natural forest/shrubland/duneland cover.	Provides coastal to inland habitat for both aquatic and terrestrial indigenous species.	Management considerations when working around riparian strips to prevent runoff and physical damage from operations while harvesting.	Ideally done by selectively thinning existing 7-year-old pine crop over 10–15 years and interplanting pockets of native species to provide seed sources for natural regeneration. Maximum of $15K/ha for restoration planting. Costs associated with managing operations close to riparian strips difficult to estimate.	
	Weed and pest control.	Allows for native regeneration from plantings through improved survival and growth rates. Prevents weed seed banks forming. Benefits native birds, amphibians, reptiles, invertebrates, and palatable vegetation.	N/A	$1.33 + $3.23 = $4.56/ha/yr = $730/yr.	

Options	Activity	Indigenous biodiversity benefits	Management and production implications[32]	Costs	Ranking of future options
Option 3. Refine harvesting methods for biodiversity benefits within areas of productive plantation forest.	Washing vehicles down	Prevents spreading invasive weeds	Already being done	N/A	Ranking: 3 Apart from actions already being taken, there is a low likelihood of protecting or enhancing understorey vegetation. Inefficiencies introduced by not clear-felling rotation forestry would be costly, and many understorey biodiversity benefits would only be temporary. As an industry, forestry companies are challenging district councils' classifications of native understorey vegetation under production forest as 'significant', so generally will not work toward protecting understorey vegetation established within a production rotation. Total ongoing costs already being spent but not defined.
	Avoid sensitive areas	Protects existing biodiversity	Being done around swamps or areas with known rare or threatened species Nothing currently identified in Tangimoana forest.	N/A	
	Protecting or enhancing some elements of understorey vegetation, i.e. leave tall pine stumps for epiphytic plant establishment above deer browse height or protecting vulnerable areas with forest slash to prevent deer access where palatable native plants may be established (or eradicate deer).	Extends habitat for some indigenous species that are mobile or colonize new areas rapidly.	Management challenges and production inefficiencies introduced by not clear felling. Consider a shift to more valuable niche forest crops with selective harvesting over time.	Costs would include disruption to felling operations if some trees were not harvested or cut tall stumps (unless individual trees were low-value due to poor form), or if slash needed to be moved. Clear-felling creates efficiencies of scale.	

Options	Activity	Indigenous biodiversity benefits	Management and production implications[32]	Costs	Ranking of future options
Option 4. Help to protect and enhance Tawhirihoe Scientific Reserve (152 ha)	Earthworks to expose summer water tables and topography for ephemeral wetland species. Optimum period for creating wetlands is at about 10-year intervals. New wetlands are most successful when within 1 km of adjacent existing wetland habitat.	Creates connectivity in time and space. Enhances biodiversity by allowing native flora and fauna to naturally colonize new areas.	NA	Approximately $180/hr = $1,260 for a day's work (use $1260 for cost estimate). Likely to also require some transplanting or planting of some native species ($15K/ha).	Ranking: 4 As a general rule, Ernslaw One prefers to undertake any equivalence work within their own estate (J Sinclair pers. comm.). Consent from DOC and a resource consent would be required from MDC as no earthworks are permitted in a SNA/ONL. **Cost in 1st year is $4,973 (earthworks, tree felling, barrier and signage placement and weed and pest control) + plan preparation and resource consent applications (estimated $20-$50K). Ongoing cost is 4.56/ha/yr+***. *will also require new scrapings every 10 years
	Putting barriers and signs in place to restrict vehicle access.	Help to manage dune stability and protect indigenous biodiversity from disturbance.	N/A	Cost is $1,260 per day for digger to place barriers (logs) and $500 for signage. (use $1,260 for one-off 1 day of log placement + $500 for signage).	
	Weed and pest control.	Allows for native regeneration. Prevents weed seed banks forming. Benefits native birds, amphibians, reptiles, invertebrates and palatable vegetation.	N/A	$1.33 (weed control) + $3.23 (pest control) = 4.56/ha/yr = $693/yr; however, monitoring and control is being done by DOC so an additional amount may not be required.	
	Transition from non-native to natives at rear of Reserve where some pine trees remain.	Extend habitat for indigenous biodiversity.	Assume pines in the reserve are not part of a productive unit.	Approximately $75/hr for manual felling and $300/hr for a felling machine = $2,100 per day (use $1,260 for one-off cost estimate).	

6 Discussion

Before the 1940s a coastal mosaic of ecosystems at Tangimoana was converted to transgressive dunes by burning and removal of native plant cover (Hesp 2001). Non-native pine plantations were then established to stabilise the area, including naturally mobile dunelands, to protect cleared, drained farmland in the lee of the dunes. While most of these plantations are harvested on a 25–30-year-cycle, a strip of retained coastal plantation forest forms a shelter belt to prevent re-mobilisation of the dunes. The Tangimoana Forest is a valuable case study to explore the challenges and opportunities of restoring native habitats in plantation forestry landscapes for several reasons: the forestry company has FSC certification, the forest is within an extremely depauperate landscape (in terms of native biodiversity), and the new landowners have aspirations to weave together production and the environment, with a focus on wetland habitats. Four options have been identified to enhance native biodiversity within, or adjacent to, Tangimoana forest. Tabulation of costs and benefits, indigenous environmental, management and production implications, and ongoing financial costs, informed ranking of the four options (Table 3).

The best option was restoration within retained plantation forest. This approach provided medium- to longer-term indigenous biodiversity benefits with low management and production implications and costs. Substantial biodiversity gains can be made because current biodiversity values within the retained plantation forest at Tangimoana are severely limited by lack of light penetration to the forest floor, dense layer of pine needles and pest animal browse. However, there are patches of native plants (particularly ferns, including epiphytic ferns, and scrubland species) to build on, and these are linked to light, structural complexity of old trees, and soil moisture (often small hollows). The current intact forest canopy is also protecting biodiversity by limiting invasion of aggressive weeds (such as acacia). Most important, the lack of disturbance or fertilisation is also protecting soil litter, water quality, and drainage profiles. This contrasts with drained, cultivated lands, without undisturbed leaf litter layers, tall canopy or coarse wood, that typify adjacent dairy farming and cropping operations.

The twin advantages of lack of disturbance and existing forest structure create the potential to transition parts of the retained plantation forest to native coastal buffers that maintain the primary function of sand stabilisation, while also allowing creation of stable rear-dune habitats such as wetlands/swamps, scrubland and forest. These would complement the less stable, parabolic dune and dune slack ephemeral wetland habitats found in the adjacent Tawhirihoe Scientific Reserve. The Coastal Buffers project led by Tane's Tree Trust (which the Coastal Restoration Trust is supporting) is testing techniques to transition failing plantation coastal forest margins to resilient permanent native buffers https://www.coastalrestorationtrust.org.nz/projects/coastal-buffers/. Collaboration with this project would help similar work within the retained plantation forest at Tangimoana.

The second-ranked option involves connecting the current retained coastal plantation forest to the inland Pukepuke lagoon. For landscape-scale benefits, connectivity over space and time needs to be considered alongside creation and protection of a range of dune habitats. Dune movement, dune slack wetland, rear dune scrubland, and forest development were all likely to be part of the natural successional processes that occurred before human intervention. Although many of the terrestrial species within this shifting mosaic have good dispersal abilities or long-lived seed banks, the importance of habitat connectivity is probably variable across sand dune habitats, and the heavy fragmentation of the current landscape means enhancing connectivity is likely to reap benefits. Connectivity is critical for aquatic species too, such as diadromous eels and galaxiid (whitebait) that currently use the outflow from Pukepuke lagoon to the coast for migration (Wildlands 2017 draft document). Most of the last Kahikatea stand remaining on the Manawatu plains was logged 100 years ago (Esler & Greenwood 1968). Opportunities to restore habitats like this for future generations are difficult to achieve as land fragmentation increases and land-use intensifies. The Pukepuke lagoon-to-coast connection is one of few areas along the Foxton Ecological District coastline that could achieve this. However, this option has the highest costs; it would split the productive forest unit in half, with significant forest management and production implications, and significant ongoing lost opportunity costs (see Table 3).

The third-ranked option is to refine harvesting methods and replant areas for biodiversity benefits within the productive forest. While this option has relatively low management, and low to moderate production and financial costs, longer-term biodiversity benefits are limited to those species that can move or disperse quickly when areas are harvested. Forestry companies do not protect understorey vegetation or habitat features (such as snags) during a rotation because they restrict flexibility in future harvesting operations. For example, as an industry, forestry companies are challenging district councils over classifications of native understorey vegetation under production forest as 'significant'. However, three actions that can be cost effective, providing both biodiversity and production benefits, are to: (1) increase biosecurity work to prevent new weeds establishing (e.g. on machinery); (2) restrict the spread of existing weeds (especially weeds that have long-lived seed banks); (3) modify the contours of fire-fighting ponds so they are more valuable habitat for a wider variety of native plant and animal wetland species as well as enhancing their safety to people and vehicles.

The final option is to help protect and enhance Tawhirihoe Scientific Reserve. Ernslaw One machinery and expertise could assist this neighbouring area where the priority is conservation. However, while management, production, and financial costs would be low, Ernslaw One prefers to undertake any equivalence work within their own estate (Sinclair, pers. comm.). Further, significant resources are likely required to jointly plan and implement the project with Department of Conservation, along with gaining potential resource consents for earthworks.

Ultimately, the balance between promoting indigenous biodiversity within the existing retained plantation forest, in a new ecological corridor in areas of currently productive forestry, within existing productive forest, or putting resources into the existing Tawhirihoe Scientific Reserve, will be determined by the preferences of the landowners (Rangitane o Manawatu), the leaseholders (Ernslaw One Ltd), and the land managers (DOC) of the respective areas. Market and social forces increasingly drive land management decisions that enhance and protect water quality and native biodiversity across a range of land uses. Forest Stewardship Council certification is one such force that provides market benefits for conservation, restoration, and the reconnection of native biodiversity across landscapes like the Manawatu plains that are virtually devoid of indigenous flora and fauna. Areas of retained plantation forest within such landscapes are one of our best opportunities to regain areas in which our unique biodiversity can be restored and promoted.

7 Conclusions

Retained plantation forest at Tangimoana currently supports very limited indigenous plant and animal biodiversity, despite being included as a proportion of the overall plantation forestry management unit to be restored to natural forest cover under the current Forest Stewardship Council certification guidelines. The pines generally form a very dense canopy that allows very little groundcover but achieves the primary purpose of protecting inland plantations. However, there is significant potential to enhance biodiversity values in the retained forest and in adjacent areas by restoring a mosaic of duneland habitats within, and adjacent to, the retained forest, particularly in the moist hollows (and fire-fighting ponds) where sparse populations of native flora and fauna are already present.

Based on consideration of past and present habitats and landscape processes, we identified four options that could enhance indigenous biodiversity within the Tangimoana Forest management area and adjacent Tawhirihoe Scientific Reserve. Three actions are 'on-site' habitat creation initiatives within Ernslaw One's forest, and the fourth involves input into an adjacent conservation area. We have also compared costs to indicate the relative initial and ongoing inputs required to carry out each of these options. Developing indigenous dune/dune slack habitat within existing retained plantation forest appears to provide the best balance of management, production, and financial implications with significant medium- to longer-term biodiversity benefits.

8 Recommendation

Create pockets with a variety of duneland habitats within the current retained plantation forest (coastal shelter belt) at Tangimoana by promoting wetland/swampland, scrubland, and native forest. This would create a mosaic of 'stepping-stone habitats' along the coast that could be gradually enlarged while retaining the primary protection role of the shelter belt. Restoration would focus on areas where native groundcover plants are already present, and risks of weed invasion and erosion are lowest. This option would develop techniques, using an adaptive experimental approach involving earthworks, targeted tree poisoning and/or removal/felling and deliberate placement of slash, limited restorative planting, and weed and pest control. This approach has the advantage of enhancing biodiversity values without removing production forest and could be started immediately. This approach complements the restoration of seaward areas to lower foredunes using native species and would be enhanced by targeted management to reduce the spread of weeds, particularly along roads (broom) and from foredunes (acacia).

9 Acknowledgements

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Appendix 1 – Species list for Tangimoana Forest and surrounding areas (non-native*)

	Scientific name	Common name
	Plants	
*	*Acacia sophorae*	Acacia
	Dodonaea viscosa	Akeake
*	*Rubus fruticosus*	Blackberry
*	*Pinus mugo*	Bog pine
*	*Lycium ferocissimum*	Boxthorn
	Pteridium esculentum	Bracken
*	*Cytisus scoparius*	Broom
	Cordyline australis	Cabbage tree
	Ficinia nodosa	Club sedge
*	*Pinus contorta*	Contorta
*	*Equisetum arvense*	Field horsetail
	Phormium tenax	Flax
*	*Ulex europaeus*	Gorse
	Asplenium flaccidum	Hanging spleenwort
	Elaeocarpus dentatus	Hīnau
*	*Lonicera japonica*	Japanese honeysuckle
	Apodasmia similis	Jointed wire-rush
	Dacycarpus dacrydioides	Kahikatea
	Pennantia corymbosa	Kaikōmako
	Weinmannia racemosa	Kamahi
	Kunzea ericoides	Kānuka
	Dysoxylum spectabile	Kohekohe
	Sophora tetraptera	Kowhai
	Pyrrosia elaeagnifolia	Leather-leaf fern
*	*Cupressus macrocarpa*	Macrocarpa
	Melicytus ramiflorus	Māhoe
	Leptospermum scoparium	Mānuka
*	*Ammophila arenaria*	Marram grass
	Discaria toumatou	Matagouri
	Prumnopitys taxifolia	Mataī
	Limosella lineata	Mudwort
	Carmichaelia australis	Native broom
	Tetragonia tetragonoides	New Zealand spinach
	Myoporum laetum	Ngaio

	Scientific name	Common name
	Metrosideros robusta	Northern Rātā
*	*Cortaderia selloana*	Pampas
	Ficinia spiralis	Pīngao
*	*Senecio glastifolius*	Pink ragwort
	Melicope simplex	Poataniwha
	Laurelia novae-zelandiae	Pukatea
*	*Pinus radiata*	Radiata pine
*	*Pinus pinaster*	maritime pine
	Typha orientalis	Raupō
	Knightia excelsa	Rewarewa
	Dacrydium cupressinum	Rimu
	Coprosma acerosa	Sand coprosma
	Pimelea arenaria	Sand daphne
	Eleocharis neozelandica	Sand spike sedge
	Asplenium oblongifolium	Shining spleenwort
	Asplenium polyodon	Sickle spleenwort
	Spinifex sericeus	Spinifex
	Syzygium maire	Swamp Maire
	Ozothamnus leptophyllus	Tauhinu
	Beilshmieida tawa	Tawa
	Alectryon excelsus	Titoki
	Austroderia richardii	Toetoe
	Podocarpus totara	Tōtara
	Steblus heterophyllus	Turepo
	Coriaria arborea var. arborea	Tutu
	Animals	
	Leiopelma archeyi	Archey's frog
	Botaurus poiciloptilus	Bittern
	Phalacrocorax carbo	Black shag
	Larus bulleri	Black-billed gull
*	*Turdus merula*	Blackbird
*	*Aceria genistae*	Broom gall mite
*	*Callipepla californica*	Californian quail
*	*Felis catus*	Cat
*	*Fringilla coelebs*	Chaffinch
	Hoplodactylus maculatus	Common gecko
	Oligosoma nigriplantare	Common skink
*	*Prunella modularis*	Dunnock

	Scientific name	Common name
	Falco novaeseelandiae	New Zealand Falcon
	Rhipidura fuliginosa	Fantail
*	*Mustela putorius furo*	Ferret
	Hoplodactylus chrysosireticus	Gold-striped gecko
*	*Carduelis chloris*	Greenfinch
	Circus apporximans	Harrier Hawk or swamp hawk
*	*Erinaceus europaeus*	Hedgehog
	Leiopelma hochstetteri	Hochstetter frog
	Prionoplus reticularis	Huhu beetle
	Latrodectus katipo	Katipō spider
	Neochanna apoda	Kōwaro or Brown mudfish
	Powelliphanta traversi	Travers' land snail
	Anguilla dieffenbachii	Long finned eel
	Chalinolobus tuberculatus	Long-tailed bat
*	*Cymnorhina tibicen*	Magpie
*	*Anas platyrhynchos*	Mallard
	Apteryx australis	North Island brown kiwi
*	*Phasianus colchicus*	Pheasant
*	*Trichosurus vulpecula*	Possum
*	*Oryctolagus cuniculus*	Rabbit
*	*Rattus rattus*	Rat
*	*Cervus unicolor*	Samba deer
	Ericodesma aerodana	Sand daphne moth
	Anguilla australis	Short finned eel
	Zosterops lateralis	Silvereye
	Larus dominicanus	Southern black-backed gull
*	*Passer domesticus*	Sparrow
	Platalea regia	Spoonbill
*	*Mustela erminea*	Stoat
*	*Turdus philomelos*	Thrush
*	*Mustela nivalis*	Weasel
*	*Emberiza citrinella*	Yellowhammer

Appendix 2 - Predicted past and actual present maps from Maseyk (2007)

https://www.horizons.govt.nz/HRC/media/Media/One%20Plan%20Documents/Past-and-Current-Indigenous-Vegetation-Cover-and-the-Justification-for-the-protection-of-Terrestrial-Bio-in-the-MW-Reg.pdf?ext=.pdf.

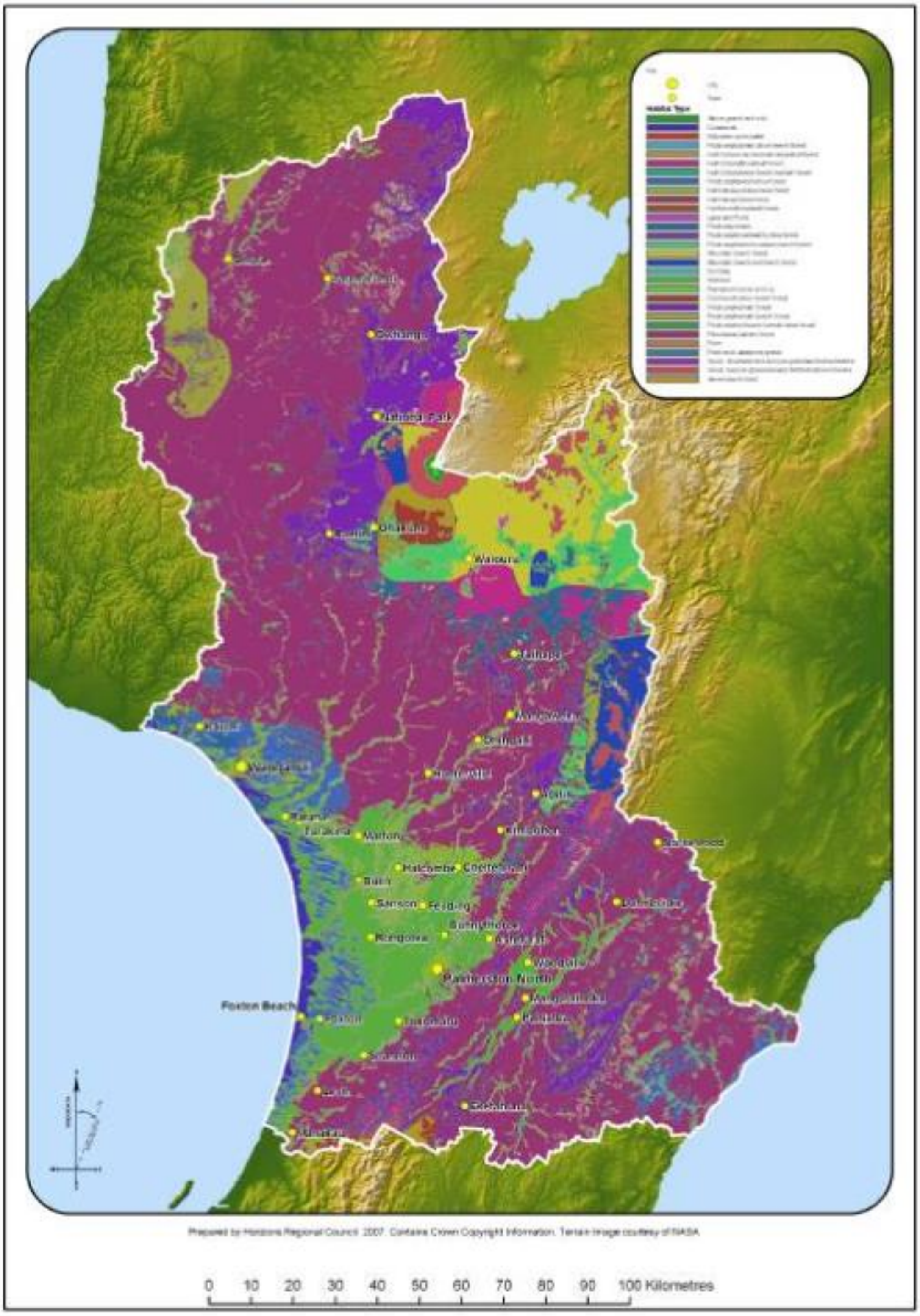

Figure 3.1: Predicted previous extent of indigenous vegetation defined by habitat type in the Manawatu-Wanganui Region.

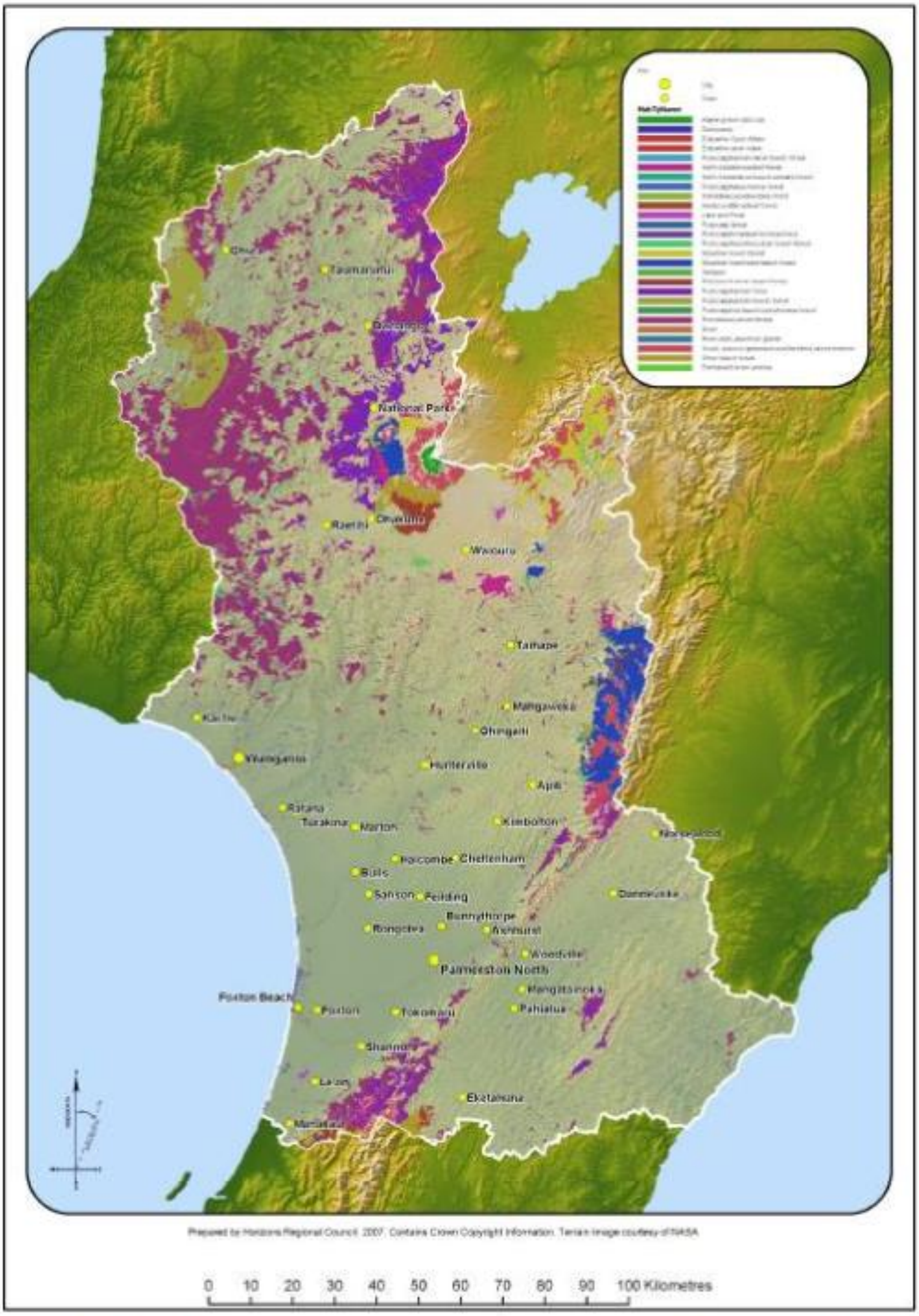

Figure 3.2: Current extent of indigenous vegetation cover defined by habitat type in the Manawatu-Wanganui Region.

Appendix 3 – Photos along the Pukepuke outlet from Pukepuke lagoon to the coast


Looking east towards Pukepuke lagoon – Paul Horton in image measuring field horsetail before releasing biocontrol agents (left) and west towards the coast with acacia and raupō (right).


Looking east away from the coastline (left) and where the Pukepuke lagoon outlet reaches the coast (right).


Where the Pukepuke outlet reaches the coast.